PERFORMANCE AND CHARACTERIZATION OF REVERSE OSMOSIS (RO) MEMBRANES IN DESALINATION PROCESS FOR MALAYSIA’S SEAWATER

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DISSERTATION SUBMITTED IN PARTIAL FULLFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF ENGINEERING

FACULTY OF ENGINEERING AND BUILD ENVIROMENT
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2013

ABSTRACT

This research is to determine and identify the seawater's parameters, define the flux and salt rejection R_S rate, and study the energy correlation with the RO membrane systems. The United Nations Environment Programmed (UNEP) calculated from now until 2027 approximately 1/3 of the world's population will suffer serious water scarcity problems. This is due to the rising demand for fresh water caused by world-wide population growth and also contamination of industrial and agricultural. Malaysia as one of the rapidly developing country also got the risk of water scarcity and needs to investigate the desalination by using RO membrane as alternative of fresh water sources. The major factors to be concerned are the seawater quality parameters, energy usage and membrane fouling. Desalination process, driven by renewable energies as an alternative power sources had become current trends due to its feasible and reliable study field. For the experimental methodology, characterization of the seawater's parameters was done by using Inductive Couple Plasma Mass Spectrometry equipment test. The pure water permeation and seawater flux, and salt rejection R_S was determined from the reverse osmosis (RO) water and seawater samples at room temperature with a Sterlitech HP4750 (Sterlitech Corporation, WA) dead-end filtration. The results obtained, showed that the flux and salt rejection rate of the membrane increased linearly and directly proportional to the net operating pressure. Thus, water flows in the reverse direction to the natural flow across the membrane, leaving the dissolved salts behind with an increase in salt concentration. VPSEM characterization verified that membrane with good pores size formation and interconnectivity show good permeation of flux and salt rejection. As the TDS goal is 1000mg/l (fresh water), the Polyamide RO AK membrane is the best membrane performance accordingly to its highest flux ratio and salt rejection rate compared to the net operating pressure. For the wind energy as an alternative renewable energy of desalination process, at wind speed data of 5.56 – 8.33 m/s can produce power from 30 to 100 kW. Based on this experimental data of membrane performance Polyamide RO AK, it's sufficient and reliable to generate power as desired by Pulau Besar 21.65 kW, Teluk Kemang 21.32kW and Pulau Melaka 20.73kW.

ABSTRAK

Kajian ini dijalankan adalah untuk mengenalpasti parameter air laut, menentukan fluks dan kadar singkiran garam. Juga untuk mengkaji hubungan di antara tenaga yang diperlukan dengan operasi tekanan sistem membran RO. Laporan oleh (UNEP) menganggarkan bahawa dari tahun semasa hingga 2027, kira-kira 1/3 penduduk dunia akan mengalami masalah kekurangan bekalan air mentah. Ini adalah disebabkan oleh pertambahan bilangan penduduk dan pembangunan pesat yang menyumbang kepada pencemaran. Negara Malaysia sebagai antara yang sedang membangun juga mempunyai potensi kekurangan bekalan air mentah. Oleh kerana kajian proses membran RO air laut, masih kurang dilakukan, inisiatif telah diambil untuk kajian ini. Antara perkara penting yang perlu dititikberatkan dalam proses penyulingan air laut menggunakan membran RO ialah kualiti bahan mentah, penggunaan tenaga dan penurunan kadar fluks. Untuk kajian ini, parameter air laut dianalisis menggunakan ICPMS, manakala fluks air RO dan air laut, ditentukan menggunakan sel uji *dead end* model Sterlitech HP4750. Keputusan menunjukan bahawa fluks dan penyingkiran garam dari air laut adalah berkadar langsung dengan tekanan operasi sistem membran RO. Ini adalah disebabkan aliran keluar masuk secara songsang melalui membran RO telah memisahkan butir-butir garam dalam *retenteate*. Imej yang ditunjukkan oleh VPSEM, pembentukan liang dan saiz yang bagus amat mempengaruhi kebolehupayaan untuk peningkatan fluks dan kadar penyingkiran garam. Merujuk kepada target jumlah kandungan garam 1000mg/l, membran RO Polyamide AK adalah yang terbaik dari segi fluks yang tinggi dan kebolehupayaan menyingkir garam dalam kadar yang besar. Hasil untuk kajian sumber tenaga yang boleh diperbaharui, tenaga angin adalah sangat sesuai untuk membekalkan tenaga elektrik melalui turbin angin kepada operasi membran RO. Pada kadar kelajuan angin 5.56 – 8.33 m/s, sistem turbin angin boleh menghasilkan tenaga pada kadar 30 hingga 100 kW. Ini adalah mencukupi kerana tenaga yang diperlukan bagi setiap sample air laut ialah Pulau Besar 21.65 kW, Teluk Kemang 21.32kW dan Pulau Melaka 20.73kW sahaja.

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J	flux (L/m^2.h)
V	volume (L)
A	surface area (m^2)
Δt	permeation time (h)
R_s	salt rejection rate (%)
$C_{permeate}$	ion concentration in the permeate (mg/l)
C_{feed}	ion concentration in the feed solution (mg/l)
$C_{concentrate}$	ion concentration in the concentrate (mg/l)
wt%	weight percent for chemical per basis
W_a	weight after (gm)
W_b	weight before (gm)
L	liter (L)
H	total head (m)
P	net operating pressure (bar)
S.G	sea water specific gravity (1.025)
P_P	pump power (kW)
Q	flow capacity (m^3/h)
ρ	sea water density 1025 (kg/m^3)
g	gravity (9.81 m/s^2)

CHAPTER 1

INTRODUCTION

1.1 Background of Study

1.1.1 Fresh water from sea water desalination

Water is the backbone of the global economy, with sustainable high quality supplies being vital for agriculture, industry, recreation, energy production, and domestic consumption. Matin et al. (2011) had discovered that for the past a few decades, clean water supplies have become a lot more critical due to excessive use and increasing contamination of natural water sources. Moreover, the demand for drinking water in the world is increasing and regulations on drinking water quality have become a lot more stringent.

The U.S. Geological Survey found that 96.5% of Earth’s water is located in seas and oceans and 1.7% of Earth’s water is located in the ice caps. Approximately 0.8% is considered to be fresh water. The remaining percentage is made up of brackish water, slightly salty water found as surface water in estuaries and as groundwater in salty aquifers. Water shortages have plagued many communities, and humans have long searched for a solution to Earth’s meager fresh water supplies (Lauren et al. 2009).

For most, solutions such as water conservation and water transfer or dam construction are not sufficient methods to cope with increasing demand and, in many cases, decreasing supply. Traditional fresh water resources such as lakes, rivers, and groundwater are overused or misused; as a result, these resources are either diminishing or becoming saline. Thus, desalination is not a new concept, the idea of turning salt water into fresh water has been developed and used for centuries. (Lauren et al. 2009).

Matin et al. (2011) had reported that by improving the effectiveness and efficiency of water purification technology, to produce clean water and protect the environment in a sustainable manner, is considered by many as perhaps the main challenge of the 21st century. Therefore, intensive efforts are underway throughout the world to avert this looming crisis with conservation of the existing limited fresh water supply and conversion of the abundantly available seawater through various desalting technologies.

Thus, reverse osmosis RO is considered as the simplest and most efficient technique for seawater desalination purposes. It is reported that membrane-based desalination accounts for about 44% of the installed capacity of water desalination in the world (Matin et al. 2011).

Matin et al. (2011) reported that one of the major goals of membrane research and the desalination industry has been to enhance, or at least maintain, water flux without sacrificing salt rejection over long periods in order to increase efficiency and reduce the cost of operation.

1.1.2 Reverse osmosis (RO) technology

Akili et al. (2008) reported that is the reverse osmosis (RO) process, the osmotic pressure is overcome by applying external pressure higher than the osmotic pressure on the seawater. Thus, water flows in the reverse direction to the natural flow across the membrane, leaving the dissolved salts behind with an increase in salt concentration. No heating or phase separation change is necessary. The major energy required for desalting is for pressurizing the seawater feed. A typical large seawater RO plant consists of four major components: feed water pre-treatment, high pressure pumping, membrane separation, and permeate post-treatment.

Pretreatment is needed to eliminate the undesirable constituents in the seawater, which would otherwise cause membrane fouling. A typical pretreatment includes chlorination, coagulation, acid addition, multi-media filtration, micron cartridge filtration, and dechlorination. The type of pretreatment to be used largely depends on the feed water characteristics, membrane type and configuration, recovery ratio, and product water quality.

High pressure stainless steel pumps raise the pretreated feed water to a pressure appropriate to the RO membranes so that water can pass through them and the salts can be rejected. The membrane must be able to withstand the drop of the entire pressure across it. A relatively small amount of salts passes through the membrane and appear in the permeate. There are membranes available which are suitable for pump operation up to 84 kg/cm^2 discharge pressure. Centrifugal pumps are generally used for this application. This pressure ranges from 50 to 80 bar for seawater, depending on the salt content of the feed water.

Two developments have helped to reduce the operating costs of RO plants during the past decade, the development of membranes that can operate efficiently with longer duration, and the use of energy recovery devices. The devices are connected to the concentrated stream as it leaves the pressure vessel. The concentrated brine loses only about 1-4 bar relative to the applied pressure from the high pressure pump. The devices are mechanical and generally consist of turbines or pumps of some type that can convert a pressure drop to rotating energy (Akili et al. 2008).

1.1.3 Desalination technology

Akili et al. (2008) claimed that, seawater is unsuitable for human consumption and for industrial and agricultural uses. By removing salt from the virtually unlimited supply of seawater, desalination has emerged as an important source of fresh water. Today, some countries depend on desalination technologies for the purpose of meeting their fresh water requirements. In particular, in the Middle East, seawater desalination is a vital and dependable fresh water resource in countries such as Saudi Arabia, United

Arab Emirates, and Kuwait. Furthermore, it is likely that desalination will continue to grow in popularity in the Middle East.

Overall, it is estimated that over 75 million people worldwide obtain fresh water by desalinating seawater or brackish water. The IDA Desalting Inventory 2004 Report shows that at the end of 2002, installed and contracted brackish and seawater desalination plants worldwide totaled 17,348 units in 10,350 desalination plants with a total capacity of 37.75 million m^3/day of fresh water. The five world leading countries by desalination capacity are Saudi Arabia (17.4%), USA (16.2%), the United Arab Emirates (14.7%), Spain (6.4%), and Kuwait (5.8%). In 2001, seawater and brackish water accounted for about 60% and 40%, respectively, of all desalinated water sources in the world (Zhao and Zou, 2011).

A seawater desalination process separates saline seawater into two streams, a fresh water stream containing a low concentration of dissolved salts and a concentrated brine stream. This process requires some form of energy to desalinate, and utilizes several different technologies for separation. A variety of desalination technologies has been developed over the years on the basis of thermal distillation, membrane separation, freezing and electro dialysis (Akili et al. 2008).

Desalination processes significantly contribute to solve the problem of water shortage. By supplying water for municipal, tourist, agricultural and industrial uses, desalination plants preserve and extend natural water resources freeing up water for agriculture, riverbed reclamation, recreational areas and forest (Macedonio et al. 2011).

1.2 Problem Statement

Catherine (2009) found that, almost three billion people around the world have no access to clean drinking water. This is based on the World Water Council, report which stated that by 2020, the world will be about 17% short of the fresh water needed to sustain the world population. Moreover, about 1.76 billion people live in areas already facing a high degree of lacking water.

From Carta et al. (2003) had found that The United Nations Environment Programmed (UNEP) calculates that from now until 2027 approximately one-third of the world’s population will suffer serious water scarcity problems. This is due to the rising demand for fresh water caused by world-wide population growth. The worsening is the result of contamination and the increasing industrial and agricultural demands on such resources. The consequences of water scarcity will be especially felt in arid and semiarid areas of the planet, but they will also be noticeable in coastal regions undergoing rapid growth, as well as in the larger cities in the developing world.

Besides that, Akili et al. (2008) had reported that, nowadays some countries depend on desalination technologies for the purpose of meeting their fresh water requirements. In particular, in the Middle East, seawater desalination is a vital and dependable fresh water resource in countries such as Saudi Arabia, United Arab Emirates, and Kuwait. Furthermore, it is likely that desalination will continue to grow in popularity in the Middle East. Overall, it is estimated that over 75 million people worldwide obtain fresh water by desalinating seawater or brackish water.

From Lauren et al. (2009) mentioned that 96.5% of Earth’s water is located in seas and oceans and 1.7% of Earth’s water is located in the ice caps and approximately 0.8% is considered to be fresh water. Hence, Malaysia country is also facing the problem and impact of freshwater supply shortage.

Malaysia as one of the rapid develop country also needs to investigate the desalination by using RO membrane as precaution methods if there is any risks for lacking of fresh water resources due to community demands and pollutions. This is reliable since there are a lot of seawater sources and also there is no data shown for these studies. The major factor to be concerned is the feed or seawater quality parameters and energy usage of RO membrane for seawater desalination.

Matin et al. (2011) also mentioned that there is a major problem related to RO applications in desalination is membrane fouling that negatively affects the performance efficiency in RO plants. Fouling is caused by solute adsorbing irreversibly or reversibly onto the surface of the membrane or within the pores of the membrane. It usually causes serious decline in the flux and quality of the permeate, ultimately resulting in an increase in the operating pressure with time.

Besides that, another critical problem needs to be considered for seawater desalination is membrane scaling (or inorganic fouling) caused by salt precipitation, which have been intensively studied. The main items need to be concern is that RO still hampered by at least three key obstacles membrane fouling, high energy consumption and limited water recovery (Zhao and Zou 2011).

Akili et al. (2008) also had highlighted that the energy consumption in all desalination processes is much higher than the thermodynamic minimum requirement. Energy cost is the major component of the operating cost of a desalination plant. Research under this topic is focused on reduction in energy consumption and the use of cheap alternative energy sources. Methods need to be developed for economically and effectively combining desalination with renewable energy systems.

Desalination driven by renewable energies is an attractive combination in many regions. Its feasibility and reliability are guaranteed by innumerable designs implemented and experiences gained. In the case of seawater desalination, wind powered Reverse Osmosis (RO) is the most efficient, mature and cost-effective technology (Peñate and García-Rodríguez 2012).

From Park et al. (2011) had reported that the use of wind turbines for desalination has been proven to be economically feasible as wind technology is well advanced and coastal sites in particular often have a good wind resource. The main challenges associated with the use of wind turbines are the intermittency and fluctuations of the wind resource which occur due to turbulence and gusts over short periods of time (seconds to a few minutes) and mass air movements over long periods of time (tens to hundreds of hours). There are also some difficulties in conducting wind turbine as power producer in desalination plant, which are the progress of choosing the pump motor based on the required pressure and flow rates, the wind turbine must be sized to meet this demand according to the available wind resource and the wind turbine power curve.

1.3 Objectives

The objectives of this research are listed as following.

i. To determine and identify the seawater's parameters.

ii. To determine the flux rate and salt rejection R_S of RO membrane systems.

iii. To study the energy correlation with the RO membrane systems.

1.4 Scopes of Research

The scopes of this research are as follow.

i. Characterize the seawater's parameters by using Inductive Couple Plasma equipment test.

ii. The feed seawater to be used is from open sea sources in Malaysia.

iii. Define the flux rate and salt rejection R_S by using dead end single stage RO membrane systems with five different types of RO membrane which is TF(Thin Film) RO SE Membrane, CA (Cellulose Acetate) RO CE, Polyamide RO AD, Polyamide RO 'AG' and Polyamide RO 'AK'.

iv. Characterize the RO membrane Scanning Electron Microscopy for cross sectional area.

v. Investigate the effect of variety pressure applied on flux rate and salt rejection R_S in order to define the correlation between energy required.

vi. Study on desalination driven by renewable energies wind powered Reverse Osmosis (RO) systems.

CHAPTER 2

LITERATURES REVIEW

2.1 Reverse Osmosis (RO) Membrane

2.1.1 RO membrane's history and overviews

The concepts of osmosis and reverse osmosis have been known for many years. In fact, studies on osmosis were carried out as early as 1748 by the French scientist Nollet, and many researchers investigated these phenomena over the next two centuries. However, the use of reverse osmosis (RO) as a feasible separation process is a relatively young technology. In fact, only in the late 1950's did the work of Reid show that cellulose acetate RO membranes were capable of separating salt from water, even though the water fluxes obtained were too small to be practical. Then, in the early 1960's, Loeb and Sourirajan developed a method for making asymmetric cellulose acetate membranes with relatively high water fluxes and separations, thus making RO separations both possible and practical (Williams 2003).

In the last 20 years a lot of improvements have been made in the RO process, which are reflected in the dramatic reduction of both capital and operation costs. Most of the progress has been made through improvements in membranes themselves. These typically include better resistance to compression, longer life, higher possible recovery, improved flux, and improved salt passage. The early research was directed towards the development of a satisfactory membrane, initially for brackish water and later seawater. The development work was undertaken by companies specializing in membrane manufacturing (Akili et al. 2008).

RO is a pressure-driven process that separates two solutions with different concentrations across a semi-permeable membrane. In the RO process, a semi permeable membrane is used for separation of particles sizes of 5×10^3-1×10^4 µm, including single charge ions as such Na^+ and Cl^-. The separation is driven under high pressures, not more than 7.0 MPa for most of commercially available RO membranes in which the fluxes of water and salt through the membrane are considered viable economically, at industrial scale, if the operation is carried out at pressures 50 to 100% higher than the transmembrane osmotic pressure (Abel et al. 2007).

2.1.2 Definition of RO membranes

The reverse osmosis is define by Matin et al. (2011) as a pressure-driven membrane-based process, where the membrane (almost always polymers) acts as the heart of the process in separating the undesired constituents from a feed to obtain the desired pure product. RO membrane acts as a semi-permeable barrier that allows selective transport of a particular species (solvent, usually water) while partially or completely blocking other species (solutes, such as salt). The separation characteristics depend upon the properties of the membrane which in turn depend on the chemical structure of the membrane material.

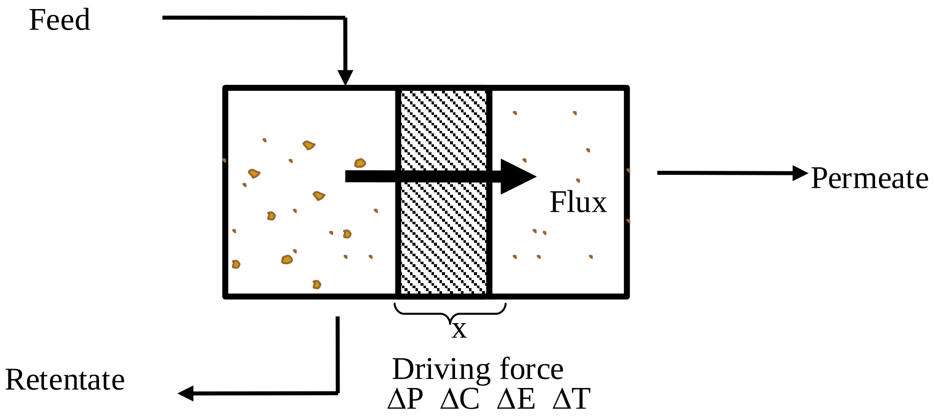

Figure 2.1 Basic membrane separation process.

Source : Norashikin et al. 2006

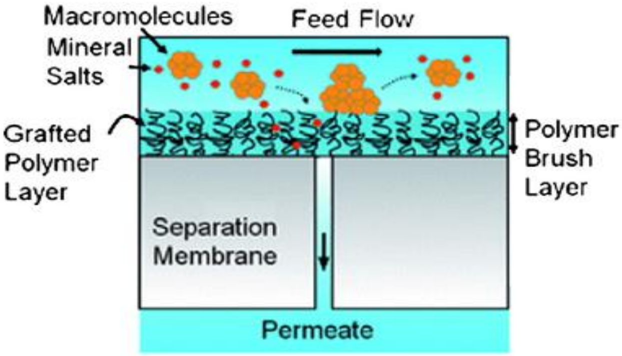

Figure 2.2 Schematic of RO membrane flux rate, salt rejection, feed, permeate and retenteate diagram.

Source : Misdan et al. 2012

Osmosis is a natural phenomenon in which a solvent (usually water) passes through a semipermeable barrier from the side with lower solute concentration to the higher solute concentration side. At equilibrium, the pressure difference between the two sides of the membrane is equal to the osmotic pressure of the solution. To reverse the flow of water (solvent), a pressure difference greater than the osmotic pressure difference is applied, separation of water from the solution occurs as pure water flows from the high concentration side to the low concentration side. This phenomenon is termed reverse osmosis (it has also been referred to as hyperfiltration).

A reverse osmosis membrane acts as the semipermeable barrier to flow in the RO process, allowing selective passage of a particular species (solvent, usually water) while partially or ompletely retaining other species which is the solute (Williams 2003).

2.1.3 RO membrane’s operation types

From Lauren et al. (2009), had discovered that, there is three major RO membranes operation which been develop and well known. These operations shown different values of salt rejection rate.

i. Cross flow operation

Membrane salt rejection is a measure of overall membrane system performance. Salt rejection through an RO membrane (cross flow operation) is nominally given by:

$$R_S = \left(1 - \frac{C_{permeate}}{C_{feed}}\right) \times 100\% \qquad (2.1)$$

Where,
C_{feed} = the ion concentration in the feed solution
$C_{permeate}$ = the ion concentration in the permeate

ii. Spiral wound operation

However, RO membranes are typically packed in a spiral wound element, where several membranes are wound around a central tube and separated by spacers. In a spiral wound element, the feed becomes increasingly concentrated from the beginning to the end of the tube and the salt rejection is described by:

$$R_S = \left(1 - \frac{C_{permeate}}{\left(\frac{C_{feed} + C_{concentrate}}{2}\right)}\right) \times 100\% \qquad (2.2)$$

Where,
C_{feed} = the ion concentration in the feed solution
$C_{permeate}$ = the ion concentration in the permeate
$C_{concentrate}$ = the ion concentration in the concentrate

iii. Dead end

When membranes are tested using dead end operation, the equations as below:

$$R_S = \left(1 - \frac{C_{permeate}}{C_{concentrate}}\right) \times 100\% \qquad (2.3)$$

Where,
$C_{permeate}$ = the ion concentration in the permeate
$C_{concentrate}$ = the ion concentration in the concentrate

From Lauren et al. (2009) stated that RO membranes are typically operated in cross flow mode and are most commonly available as spiral wound modules, where the membrane sheets are wound around an inner tube that collects the permeate. Most membranes allow filtration through pore flow, where the fluid is forced through the membrane by a positive hydrostatic pressure.

Most currently available RO membranes fall into two categories, which is asymmetric membranes containing one polymer, and thin-film, composite membranes consisting of two or more polymer layers. Asymmetric RO membranes have a very thin, permselective skin layer supported on a more porous sublayer of the same polymer; the dense skin layer determines the fluxes and selectivities of these membranes while the porous sublayer serves only as a mechanical support for the skin layer and has little effect on the membrane separation properties. Since the skin layer is very thin (from 0.1 to 1 μm), the membrane resistance to water transport is much lower and, as a result, water fluxes much higher than those through comparable symmetric membranes (Williams 2003).

From Park et al. (2011) had reported that Spiral Wound RO modules have dominated the market because of their high surface area to volume ratio, increased robustness and permeability. The challenges faced by these membranes are fouling and concentration polarization, which result in reduced flux and deterioration of permeate quality.

2.1.4 RO membrane’s advantages

Reverse osmosis (RO) is a separation process for water desalination which has some advantages in terms of saving energy, modularity, flexibility, ability to construct small size plants or even less installation space when compared to other traditional techniques, which include namely thermal processes, such as the multi-stage flash (MSF) distillation (Abel et al. 2007).

The driving force for the development and use of RO membranes is the advantages that these have over traditional separation processes such as distillation, extraction, ion exchange, and adsorption. Reverse osmosis is a pressure-driven process so no energy-intensive phase changes or potentially expensive solvents or adsorbents are needed for RO separations. Reverse osmosis is a process that is inherently simple to design and operate compared to many traditional separation processes. Also, simultaneous separation and concentration of both inorganic and organic compounds is possible with the RO process (Williams 2003).

Others than that, reverse osmosis systems have plenty of advantages. They are friendly to the environment, as they do not produce or use any harmful chemicals during the process. These systems also require a minimal amount of power. Reverse osmosis systems work well in home filtration systems because they are typically small in size. Taste of the purified water is another distinct advantage. Reverse osmosis removes dissolved minerals and other contaminants that cause water to smell unpleasant, taste poorly and take on unusual colors. Removal of dissolved minerals, metals and other particles benefits plumbing systems. There is nothing in the water to corrode pipes or collect as sediment.

From Liu et al. (2008) had claimed that The reverse osmosis (RO) process which uses polymeric membranes to achieve molecular separation excels all other methods of desalination and is the most efficient technique to desalt seawater.

The RO plant energy consumption is approximately 6-8 kW h/m^3 without energy recovery. Installing an energy recovery device reduces the energy consumption quite dramatically to 4-5 kW h/m^3. The unit energy consumption can be reduced to as low as 2 kWh/m^3. This achievement is dramatic and possible due to the innovation in the energy recovery device (Akili et al. 2008).

2.2 Desalination Process

2.2.1 History of desalination process

Cerci (2002) had reported that, there is a critical issue of fresh water shortage for the 1990s and beyond. The potable water, until recently considered to be inexpensive and plentiful is now understood to be scarce and vulnerable, and the demand for potable water is increasing. Population growth, rising living standards, industrialization, and the expansion of irrigation agriculture point out that there will be no let-up in the increasing demand for potable water in the years to come.

Desalination has long been a major source of additional potable water in many parts of the world. A worldwide survey showed in 1997 that there are about 12,500 desalination plants in the world, producing over 23 million m^3/d of fresh water. Most of these plants are in the Middle East. Saudi Arabia is the largest user of desalination with about 25% of world capacity, and the US is the second largest user with about 10% of world capacity (Cerci 2002).

In the desalination, variables such as the permeate (purified water) quantity and quality should be maximized for the most efficient and economical use of the process. Thus, desalination is not a new concept, the idea of turning salt water into fresh water has been developed and used for centuries (Abel et al. 2007).

2.2.2 Definition of desalination

Basically, Lauren et al. (2009) had defined that the desalination is a general term for the process of removing salt from water to produce fresh water. Fresh water is defined as containing less than 1000 mg/L of salts or total dissolved solids (TDS). For above 1000 mg/L, properties such as taste, color, corrosion propensity, and odor can be adversely affected.

From Catherine (2009) had reported that generally, desalination processes can be categorized into two major types, phase-change thermal and membrane process separation. Some of the phase-change processes include multi-stage flash, multiple effect boiling, vapor compression, freezing, humidification or dehumidification and solar stills. Membrane based processes include reverse osmosis (RO), membrane distillation (MD) and electro dialysis (ED). The required pressure depends on the salt concentration of the resource of saline solution, it is normally around 55 to 70 bar for seawater desalination.

Among the various desalination technologies, reverse osmosis (RO) is one of the most efficient requiring about 3-10 kWh of electric energy per m^3 of fresh water produced from seawater. The rate at which fresh water crosses the membrane is proportional to the pressure differential that exceeds the natural osmotic pressure differential. The membrane itself represents a major pressure differential to the flow of fresh water. The major energy requirement is for the initial pressurization of the feed water for seawater desalination from 55 to 70 bar (Catherine 2009).

Besides that Akili et al. (2008) had claimed that, seawater is unsuitable for human consumption and for industrial and agricultural uses. By removing salt from the virtually unlimited supply of seawater, desalination has emerged as an important source of fresh water.

Since there is many countries in the world suffer from a shortage of natural fresh water. Increasing amounts of fresh water will be required in the future as a result of the rise in population rates and enhanced living standards, together with the expansion of industrial and agricultural activities. Available fresh-water resources from rivers and groundwater are presently limited and are being increasingly depleted at an alarming rate in many places.

Due to the increasing of water shortage problems, the need for inland brackish water RO will continue to increase in future. However, the primary limitations to further application of RO inland are the cost and technical feasibility of concentrate disposal (Macedonio et al. 2011).

A variety of desalination technologies both thermally-driven and membrane based, have been increasingly employed to enhance the limited freshwater supply. Among them reverse osmosis (RO) is regarded as the most economical and popular desalination way for water production mainly due to the advancement of membrane technology (Zhao and Zou 2011).

2.3 RO Membrane in Desalination Process

The reverse osmosis (RO) process which uses polymeric membranes to achieve molecular separation excels all other methods of desalination and is the most efficient technique to desalt seawater. In order to maximize the solute separation ability and efficiency, one has to develop membranes from available polymers having suitable pore size combined with the appropriate chemical nature of the polymer. So far, two main types of polymeric reverse osmosis membranes have been developed for seawater desalination, namely asymmetric membrane and thin-film composite (TFC) membrane (Liu et al. 2008).

Major design considerations of seawater RO plants are the quantity of flux, conversion or recovery ratio, permeate salinity, membrane life, power consumption, and feed water temperature (Akili et al. 2008).

Typically energy inputs can account for 44% of the total water costs of a RO plant. While the water recoveries of single-stage desalination systems range from 40% to 60%, although second-stage RO can further increase the water recovery with an added energy and capital costs. Although most seawater sources contain 30,000-45,000 mg/L total dissolve solid (TDS), seawater reverse osmosis membranes are used to treat waters within the TDS range 10,000-60,000 mg/L. Hence, for some membranes, when operated under standard test conditions (32,000 mg/L NaCl, 5.5 MPa, 25 °C, pH 8, 8% recovery), can achieve as high as 99.7-99.8% salt rejection (Lauren et al. 2009).

2.3.1 Characterization of RO membrane performance in desalination process

Membrane salt rejection is a measure of overall membrane system performance, and membrane manufacturers typically state a specific salt rejection for each commercial membrane available. Salt rejection through an RO membrane (dead end operation) is nominally given by Lauren et al. (2009):

$$R_S = \left(1 - \frac{C_{permeate}}{C_{concentrate}}\right) \times 100\% \tag{2.3}$$

Where,

$C_{permeate}$ = the ion concentration in the permeate

$C_{concentrate}$ = the ion concentration in the concentrate

The flux (J) of solute in membrane is obtained by this equation (Norashikin, 2006) :

$$J = \frac{V}{A \times \Delta t} \tag{2.4}$$

Where,

V = volume of permeate (L)

A = membrane surface area (m^2)

Δt = permeation time (h)

2.3.2 Effect of operating pressure on RO membrane performance

Liu et al. (2008) had reported that the effect of the operating pressure on salt rejection and water flux to 3.5 wt. % NaCl aqueous solution was also determined for the TFC polyamide-urethane SW RO membrane by testing under different operating pressures. What is apparent from the graph is that, as the operating pressure increases from 3.5 to 6.0 MPa, the salt rejection ascends and levels off at 4.5 MPa, while the flux of the membrane increases almost linearly. It can be explained by the fact that the permeate flux is directly proportional to the net operating pressure, whereas the solute diffusion across the membrane on the other hand is not affected by the applied pressure, so an increase in water flux with applied pressure will result in a low salt concentration in the permeate and thereby an increase in salt rejection. While the low water permeate flow rate across the membrane would account for the fall-off in salt rejection for pressures below 4.5MPa.

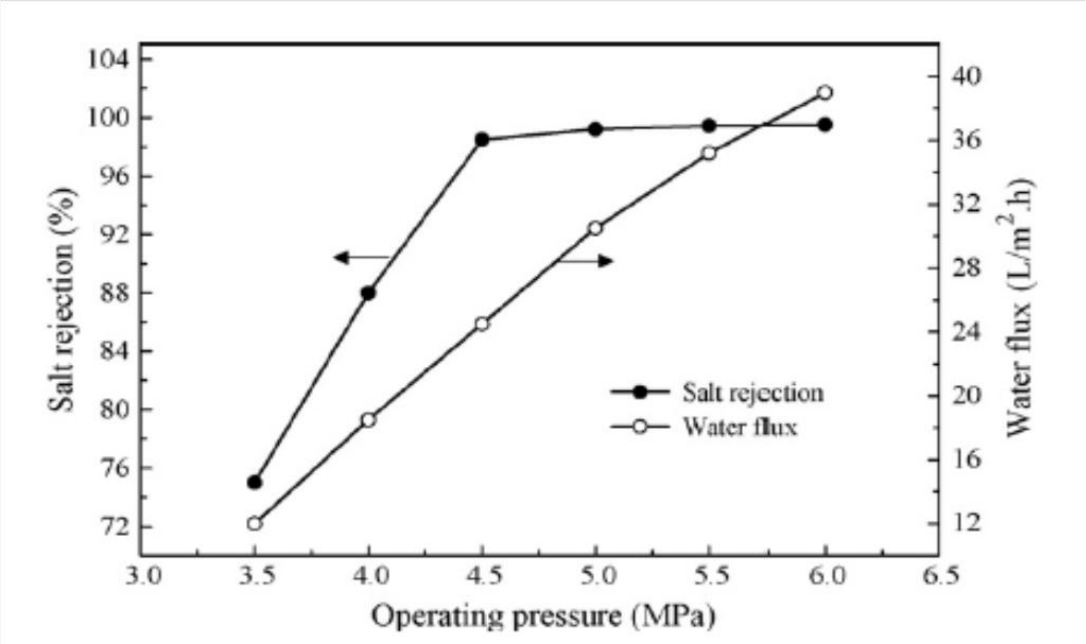

Figure 2.3 Salt rejection (%) versus operating pressure (MPa).
Source : Liu et al. 2008

2.3.3 Characterization and properties of seawater in desalination process

Seawater is a complex conglomeration of microorganisms, organic and mineral matter widely dispersed within a saline water matrix. The compounds that are susceptible to foul the RO membranes are organic and inorganic suspended solids, sand, oil, clays, bacteria, dissolved organic matters. It is likely that fouling is further enhanced when the flow conditions are such that the plank tonic organisms are crushed and so release cellular components or when pipe chlorination is insufficient to avoid the development of bacterial biofilms with the excretion of extracellular polymers (Lauren et al. 2009).

The outcomes sources for the seawater had been determined and decided to pick from west coast of Malaysia peninsular. There is three different samples to be collected from three different location. This is based on visual appearance of the seawater colour. This is clear, middle turbid and turbid. This seawater property is characterized by using inductive couple plasma. From Akgula et al. (2008), had shown as below the examples of seawater properties and parameters to be determined.

Table 2.1 Quality parameters of the seawater used in reverse osmosis systems designs

Parameter	**Unit**	**Sample 1**	**Sample 2**	**Sample 3**
pH		8.3	8.3	8.2
TDS	mg/L	37100	24400	19100
Sodium	mg/L	11544	7700	5930
Potassium	mg/L	388	276	220
Calcium	mg/L	1302	282	226
Magnesium	mg/L	415	853	646
Ammonium	mg/L	0	0	0
Strontium	mg/L	6.3	5.2	4
Barium	mg/L	0.01	0	0
Bicarbonate	mg/L	146	187	157
Chloride	mg/L	20500	13200	10420
Sulphate	mg/L	2790	1860	1490
Fluoride	mg/L	<1	<1	<1
Nitrate	mg/L	<1	<1	<1
Silica	mg/L	5	<1	<1
Iron & Manganese	mg/L	<0.1	<0.1	<0.1

Source : Akgula et al. 2008

The osmotic pressure of seawater is typically 2300-2600 kPa and can be as high as 3500 kPa. To overcome the osmotic pressure, feed pressures in seawater applications range from 6000 to 8000 kPa, whereas those in brackish water are 600-3000 kPa (Lauren et al. 2009).

Many countries have adopted national drinking water standards for specific contaminants, as well as for TDS, but the standard limits vary from country to country or from region to region within the same country. The World Health Organization (WHO) and the Gulf Drinking Water standards recommend a drinking water standard of 1000 mg/L TDS for drinking water.

2.3.4 RO membrane fouling in desalination process

For the fouling properties, mainly refers to the deposition of foulants on top of the membrane surface or within the membrane pore and can be generally categorized into inorganic fouling, colloidal fouling, organic fouling and biofouling. It must be pointed out that fouling portrays the prominent constraint in seawater desalination process. It deteriorates membrane performance and shortens its lifespan, leading to increased operation cost. For these reasons, membrane fouling control is highly recommended as an imperative way to control the economics of seawater reverse osmosis (SWRO) desalination process (Misdan et al. 2012).

RO membrane's plant fouling is caused by solute adsorbing irreversibly or reversibly onto the surface of the membrane or within the pores of the membrane. It usually causes serious decline in the flux and quality of the permeate, ultimately resulting in an increase in the operating pressure with time. From Matin et al. (2011) had reported that there are a few type of fouling RO membrane. As stated below:

i. Crystalline, deposition of inorganic material precipitating on a surface.
ii. Organic, deposition of organic substances (oil, proteins, humic substances).
iii. Particulate and colloidal, deposition of clay, silt, particulate humic substances, debris, silica.
iv. Microbiological, biofouling, adhesion and accumulation of microorganisms, forming biofilms.

Besides that, other major types of membrane fouling in RO membrane desalination process is biofouling. This is referred to as the unwanted deposition and growth of biofilms. A biofilm is an assemblage of surface-associated microbial cells that is irreversibly associated (not removed by gentle rinsing) with a surface and enclosed in a matrix of extracellular polymeric substances. The formation of biofilms may occur on a wide variety of surfaces including living tissues, indwelling medical devices, industrial or potable water system piping, or natural aquatic systems (Matin et al. 2011).

2.4 Renewable Energy Available in Seawater Desalination by RO Membrane

Desalination driven by renewable energies is an attractive combination in many regions. Its feasibility and reliability are guaranteed by innumerable designs implemented and experiences gained. Nevertheless, desalination systems driven by renewable energy technologies are usually for small capacities since, in most cases, they have been built within the framework of R&D or international cooperation projects. In addition, there are very few commercial desalination systems driven by renewable energy technologies and also their capacities are limited. Only mature and efficient technologies are suitable for medium to high scale desalination. In the case of seawater desalination, wind powered Reverse Osmosis (RO) is the most efficient, mature and cost-effective technology. However, if the use of wind power is not possible in a given arid coastal location, the second option is to use solar energy (Peñate and García-Rodríguez 2012).

Hence, Carta et al. (2003) had reported that almost all desalination plant nowadays is using fossil fuels, and thus contributes to increased levels of greenhouse gases. As the results of the environmental damage and contaminants due to of fossil fuels usage, the International Atomic Energy Agency (IAEA) had proposed another energy sources which is nuclear energy and to be used for large scale sea water desalination, but there are also some argument regarding this proposal. Instead of using nuclear energy, they also had proposed another energy which is more ecological and economical, proposing the use of renewable energy sources, fundamentally wind and solar, for small scale sea water desalination.

The major constraint of the desalination systems employing renewable energy sources that have been installed is suffering from the principal inconvenience of having to use batteries for the storage of the electrical energy produced. Consequently, they can only be used for small scale water production or need to operate in combination with a diesel generating system. Resulting problems related to the emission of contaminants into the atmosphere (Carta et al. 2003).

2.4.1 Powered RO membrane from conversion of wind turbines energy to electric energy

The use of wind turbines for desalination has been proven to be economically feasible as wind technology is well advanced and coastal sites in particular often have a good wind resource. The main challenges associated with the use of wind turbines are the intermittency and fluctuations of the wind resource which occur due to turbulence and gusts over short periods of time (seconds to a few minutes) and mass air movements over long periods of time (tens to hundreds of hours). The direct connection of a wind turbine to a RO system with no form of energy storage will inevitably result in large fluctuations in pressure and flow rate. This presents a considerable challenge for wind-powered membrane (wind-membrane) systems as membranes are designed to operate at constant operating conditions with no abrupt pressure or cross-flow variations in order to minimize damage (Park et al. 2011).

The majority of the small-scale (permeate production $\leq 25 m^3$/day) wind membrane systems that have been developed either used the electrical output from a horizontal axis wind turbine with energy storage in batteries, or the mechanical output from multivane windmills with a pressure vessel as the buffer for fluctuations. Whilst the use of deep-cycle lead acid batteries can enable uninterrupted operation, they result in increased capital and operational costs as well as lower system efficiency and decreased robustness. There have been several wind-membrane systems that operated successfully under varying flow rate and pressure with no form of energy storage (Park et al. 2011).

From Park et al. (2011) had reported that there are some difcciulties in conducting wind turbine as power producer in desalination plant. Matching the wind turbine to the membrane system is the main design challenge for a directly connected system. Having chosen the pump motor based on the required pressure and flow rates, the wind turbine must be sized to meet this demand according to the available wind resource and the wind turbine power curve. Another challenge is that there is no standard method that manufacturers are required to follow in order to measure the power curve and wind turbines are often rated at high wind speeds that are rarely experienced in the field. This makes it very difficult to accurately predict performance without actually testing the wind turbine and using high resolution wind speed data. This wind turbine was selected based on the power requirements of the pump motor and associated electronics, as well as the performance and relative cost of the wind turbine.

From Park et al. (2011) finding, the Figure 2.4 show the schematic diagram of the wind-membrane system with electrical connections (dotted lines) and water flow (solid lines) for the components of the wind-membrane system programmable power supply wind turbine motor controller micro filter RO membrane pump P1-P3 pressure transducers F1-F3 flow sensors C1-C3 conductivity sensors V1 and V2 voltage sensors I1 and I2 current sensors, pH/T: pH and temperature sensor.

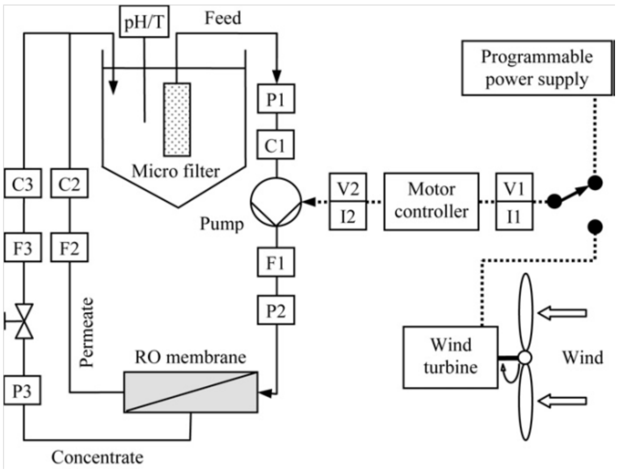

Figure 2.4 Schematic diagram of the wind-membrane system with electrical connections.

Source : Park et al. 2011

For the power performance of wind turbine and membrane system, the main aims of this study were to determine the effect of wind speed fluctuations on the performance of the wind turbine and the extent to which these can be beneficial or detrimental within a safe operating window. A power curve showing the relationship between wind speed and power output from the wind turbine was determined using the wind tunnel. Up to a wind speed of 7 m/s the relationship of power output with wind speed was linear. At higher wind speeds a combination of wind turbine furling and the power restrictions of the pump motor caused the wind turbine power curve to level off at a maximum value of 300 W. The wind turbine (rated power 1 kW at 12.5 m/s, Future Energy) and had five blades, a diameter of 1.8m and was designed to charge a 48V DC battery bank (Park et al. 2011).

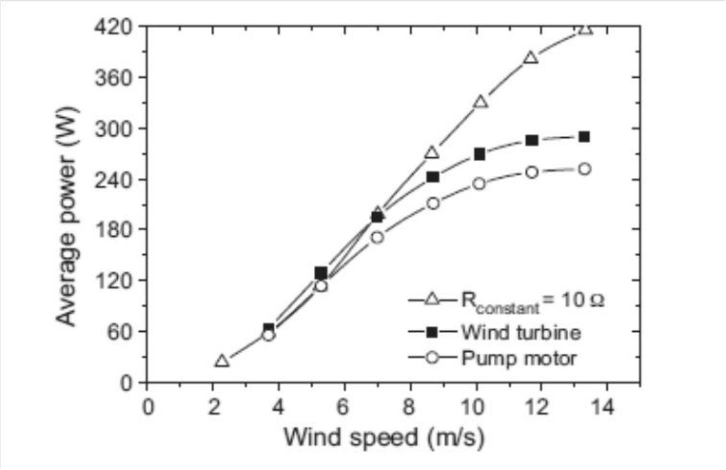

Figure 2.5 Wind turbine power curve at constant load and with the wind turbine connected to membrane system.

Source : Park et al. 2011

Beside that, for Figure 2.6, show that at steady-state conditions: constant power experiments were used to determine the steady state operating characteristics of the membrane system to form a baseline for comparison with results obtained with fluctuations. The power was held constant for 20 min during each step of 60, 120, 180, 240 and 300 W, corresponding to average wind speeds of 3.7, 5.3, 7.0, 8.7 and 13.3 m/s, respectively. Hence the operation of the membrane system is under steady state conditions, its served as a baseline for comparison with fluctuations in power. The transmembrane pressure is increased with wind power and was independent of the concentration of the feed water as it was controlled by the valve on the concentrate stream which was set at the start of each experiment. As would be expected, the concentrate NaCl followed the opposite relationship to the permeate and increased with the available power. With respect to a safe operating window, the permeate NaCl was within the WHO guideline value over the full range of operating conditions with a feed water of 2750 mg/L NaCl. With a feed water of 5500 mg/L NaCl, a minimum of

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