An-Najah National University

Energy and Environmental Engineering Department

Simulation of PV Powered RO System for Spring Water Treatment: Ain Shraish in Nablus as a Case Study.

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Abbreviations

AM	Air Mass
AC	Alternating Current
Cfu	Colony Forming Unit
Impp	Current Maximum Power Point
DC	Direct Current
ED	Electro Dialysis

kWh	Kilowatt Hour
MF	Microfiltration
MSF	Multistage Flash
NF	Nanofiltration
Voc	Open Circuit Voltage
PPM	Parts Per Million
PV	Photovoltaic
RO	Reverse Osmosis
Isc	Short Circuit Current
Si	Silicon
STC	Standard Test Conditions
TDS	Total Dissolved Solids
UF	Ultrafiltration
UN	United Nation
VC	Vapor Compression
Vmpp	Voltage Maximum Power Point
WHO	World Health Organization
Wp	Watt Peak
NDP	Net Driven Pressure

Abstract

Water and energy problem are the main issue that world suffer from it and tried to find sustainable solution for it .Palestine is one of country that have these problems because of Israeli occupation and their tough policy in water and energy sectors. One of the solutions of water problem is to exploitation of springs water where it consider as undrinkable water. in addition, in winter season water level is overflow which cause a flood in the streets. To solve this problem desalination technology is used and in this system a reverse osmosis technology is used which is powered by solar energy and it is a sustainable solution for electricity problem in rare area. Where one stage and one pass with ECO PLATINUM 440 which is Spiral-Wound element with polyamide thin-film composite membrane driven by 11 watt high pressure pump powered by 50 watt PV panel, the result was feasible in some of months and the other was not

and it depend in the amount of the solar radiation because there is no storage system in the system.

1. Chapter One

1.1 Introduction

Water is essential to life. The importance of supplying potable water can hardly be overstressed. Water is one of the most abundant resources on earth, covering three-fourths of the planet's surface. About 97% of earth's water is salt water in the oceans and 3% (about 36 million km3) is fresh water contained in the poles (in the form of ice), ground water, lakes and rivers, which supply most of human and animal needs. Lakes and rivers together contain just a little more than 0.25% of all fresh water; lakes contain most of it[1]. Unfortunately, this percent of fresh water is not sufficient to cover water demand which increases with population growth and life requirements. Safe and readily available water is important for public health, whether it used for drinking, domestic use, food production or recreational purposes. Improved water supply and sanitation, and better management of water resources, can boost county's economic growth and contribute greatly to poverty reduction. This crisis needs serious solutions to protect our planet by preserve the sources of water. So it is necessary to find technologies in order to face the challenges that the world face.

Several regions and areas around the world are facing water problems. According to UN World Water Development Report in 2019,Over 2 billion people live in countries experiencing high water stress. Although the global average water stress is only 11%, 31 countries experience water stress between 25% (which is defined as the minimum threshold of water stress) and 70%, and 22 countries are above 70% and are therefore under serious water stress [2]. One of these countries that suffer from water scarcity is Palestine, The major water resources available in Palestine are ground water and wells. But these sources are shared with (Israel), since its occupation the Palestinian Territories in 1967, Palestinians are not allowed to use more than 15% of their groundwater and are denied access to the Jordan River. Water issues in the Palestinian-Israeli peace talks are postponed and will be settled in the permanent status negotiations[3].

Nablus City has many of springs and wells and they contain contaminated in the water which effect on human health and environment, the water is treated in many ways to be drinkable water. The most promising technique for supplying fresh water in Palestine is Water Desalination, which is defined as any process that removes salts from water; it has two main technologies; thermal and membrane, among all desalination technologies, reverse osmosis (RO) is one of the most reliable technologies.

Reverse osmosis is one of the major technologies because it offers methods of producing high quality of water from brackish and seawater with lower energy consumption than other technologies. The process of reverse osmosis requires that the water be forced through a semi-permeable membrane in the opposite direction of the natural osmotic flow; leaving the dissolved particles in the more highly concentrated solution. In order for reverse osmosis to occur, the amount of force or pressure applied must exceed the osmotic pressure.

The amount of freshwater that can be recovered from the feed is limited by membrane fouling and scaling. Overall water recovery rates are 45–50% for seawater RO systems, and they can be as high as 90% in brackish water desalination systems, the reasons why should we choose RO system because it is easy to use, effective, and can quickly be installed by a local plumber. It can help get rid of any contaminants present in the water[4].

The main obstacle that faces water desalination is electricity, whereas it consumes large amount of energy and has difficult access to some regions such as wells and springs that is located in remote areas. Palestine suffers from the scarcity of non-renewable energy sources such as fossil fuels (gas and oil), high prices, and the Israeli occupation authorities, The Palestinian territories are highly dependent on electricity provided by the IEC (Israel Electrical Corporation), around 88% of total consumption. The Palestinian energy market has limited options to develop indigenous sources of electricity and Israeli restrictions have prevented the construction of power networks in large parts of Area C which comprises 60% of the West Bank[5]. While Palestine has one of the highest solar energy potentials of all the countries in the world. It enjoys over 3000 Hours of sunshine every year; with an annual average daily solar radiation intensity amounting to 5.4 kilowatt per square meter per day.

Using Renewable energy sources with Water Desalination is the most environmental and economical way to produce huge amount of fresh water whereas using traditional methods of burning fossil fuels contribute to increase greenhouse gases, especially carbon dioxide, resulting in risks to human health. These gases contribute global warming, acid rain and the widening of the ozone hole. In addition to these resources are unsustainable and will be implemented when they used over the years. Otherwise the price of the fossil fuel is increase compare to Renewable energy source.

Combining renewable energy resources with desalination technique is a good solution for water and energy crisis, if the huge energy requirement for desalination can be fulfilled by renewable energy resources like solar photovoltaic to reduce the problems due to the usage of fossil fuels. The usage of solar photovoltaic energy to run a desalination plant with reverse osmosis technology will be good solution for fresh water crisis and also at the same time for energy crisis too.

In addition, PV/RO (Photovoltaic Reverse Osmosis) has minimal environmental impacts, can be easily designed and assembled for different demand profiles using modular components and can be easily maintained and repaired.

1.2 Problem of Statement

By the time the competition of water source is increasing in the world, the costs and benefits of water use were separated, and demand increased faster than supply. In addition the worldwide distribution and management of water is very uneven, which partly explains why more the one billion people lack access to safe drinking water. These problems are growing more severe, and political conflict over water is increasing. In Palestine lacking fully utilization of available water and energy resources and the urgent need of fresh water in order to cover the demand which is accompanying the population growth, all that led us to accelerate the process of coming up with a solution of exploiting which became a necessity in the region. Furthermore, utilizing the renewable and sustainable power resources with advanced effective technologies, putting in consideration the inconvenience interfering from the Israeli side that constrict the further advance in the energy aspect. The scarcity of fresh water is considered a serious threat of human civilization, alongside insufficient and unequal distribution of sources in the world.

contaminated drinking water could result to a lot of adverse human health conditions and diseases such as cholera, diarrhea, dysentery, typhoid, polio, guinea worm, and skin infection so having an understanding of the current status of drinking water quality in any area is part of the basics required towards making wise plans and decisions on drinking water quality protection and management.

Due to the excessive water consumption and depletion of ground water that are the main source of water in Palestine, also increased demand for freshwater and to exploit brackish water in the region, that is considered one of the alternatives for ensuring a supply of drinking water in the dry period. A portable desalination device can be the solution which will produce freshwater by using reverse osmosis technology that is ranked first of the several desalination technologies that is cleared in this study. RO is very flexible in water quantity and quality, site location, and start-up and shut-down with low power requirements compared to other technologies. This method of desalination is available for remote areas that are far from electricity grid.

Saline water is not suitable for drinking and use. However, there are other factors that make water unsuitable, such as microbes, germs and pathogens. Water may also contain an increase in the proportion of mineral elements in it, making it unsuitable for use. An example is Ain Shraish, located in Nablus City, which suffers from high Potassium proportion. Therefore, the study will be about and make its water suitable for drinking and use .So to get fresh water there is a need for energy to operate the system, Palestine possesses a high potential for photovoltaic (PV) applications due to the high average annual daily solar radiation, which exceeds 5.4 kilowatt per square meter per day and the Israeli occupations, which has stifled development in all fields related to infrastructure, is another factor that makes PV applications viable due to the continuous decrease of PV modules cost and the increase in solar cell efficiency, solar photovoltaic (PV) power became the most widely owned electricity source in the world. In addition, Palestine lacks conventional energy resources such as oil and gas, and therefore must import all its energy from Israel at a relatively high cost. Consequently, utilization of PV technologies for treatment of groundwater would save hard currency and preserve the environment.

1.3 Objective

This project aims to study the following points:

1. Design a small Photovoltaic Reverse Osmosis desalination system for Ain Shraish spring in Nablus City to obtain fresh water.
2. Simulate PV/RO System in order to study the results of water quality and quantity throughout the year.
3. study the amount of energy produced by Photovoltaic (PV) system from simulation results.

2. Chapter Two

2.1 Literature Review

By years water and energy was the big challenges for all countries to obtain fresh water and electricity with easy, sustainable and economical ways. Desalination and Renewable energy are one of the solutions for these problems individually or collect them together. According to paper [6] which study small water treatment unit using Photovoltaic Powered Reverse Osmosis system, the system consists of five main components, five-micron sediment filter that is made of polypropylene, two active carbon filters with 1 -2 micrometer hole diameter, and one polyamide TFC membrane. it powered by One PV arrays panel (55 W) which tilted a 45 to the south directly coupling to a DC motor (Diaphragm), that can give pressure up to 1.2 bar and average flow rate 34.68 L/d by using water from Shraish spring located in Nablus city in West Bank. The paper study the effect of parameters as solar radiation, pump pressure, feed water temperature, TDS and recovery with permeate water.

Another paper [7] presented a design of PVRO water desalination system plant in the village of AL-Maleh in Jenin City. The simulation results show that the desalination plant will produce $10.85m^3$/day and daily production of $1m^3$ of fresh water would require 821.2Watt PV-peak power. The plant will operate for 5h/day delivering $10.85/5=2.17m^3/h$.

This project is similar to the previous systems in some points such as using RO technology and PV energy source, but it difference in another where the system is a portable device to produce fresh water, this device is the first of its kind in design also the simulation will study the characteristic of solar energy throughout the year to obtain fresh water from reverse osmosis system. The water source is Ain-Shraish spring in Nablus City which suffers from high potassium proportion. The simulation results show that the TDS decreased from 379 mg/L to 140mg/L, and the potassium decreased from 30mg/L to 16mg/L.

Paper [8], presents a Photovoltaic (PV) simulation system powering a reverse osmosis (RO) desalination unit with no energy recovery device (ERD). The simulation is carried out using commercial software, Transient System Simulation (TRNSYS). The PV system consists on solar panels (Siemens SM55) with rated power of 55 W, connected to a storage battery via DC-DC charge controller. Pump is consider as a load to this system. The RO unit is composed of one Filmtec spiral wound membrane. The Simulation results using TRNSYST software for fresh water production showed that with a continuous feed of 1.5 m3 h-1, a total capacity production of 110 m3 per year can be achieved. The effect of the main parameters in desalinated water production capacity showed that with the increase of the raw water feed flow and the PV surface, the monthly fresh water production increases. They also showed that with the increase of raw water salinity, the freshwater production decreases. This work is validated with literature experimental results.

And according to paper [9], one of the most promising technologies to produce potable water from both brackish and sea water is reverse osmosis technology powered by solar PV system. The thesis discussed the first BWRO desalination system operated by solar electric power (PV) in West Bank-Palestine precisely in Az Zubeidat where the system produces $10m^3$ of potable water per day from brackish water with TDS of 2680 mg/L using RO technology powered by solar PV generator of 5.2KWp. This system is built in village-Jordan-Valley to demonstrate the applicability of solar energy in water desalination and to provide the inhabitants with the desalinated drink water.

Paper [10] present the design and sizing of a small-scale solar photovoltaic powered reverse osmosis purification system that provides drinking water to domestic or small group in a remote area in Babil Governorate in south Iraq. The aim of this study is to estimate an optimum PV system to power the RO that produces 20 l/h (0.35 M3 /day) at constant daily load profile. The system designed based on brackish waters at a (Total dissolve solid (TDS) value of 1500-2000 mg/L) from well in mention area, The PV and solar source simulated by TRANSYS16 Software to evaluate various PV-RO system. The results indicated requires energy of approximately 216.5 Wp with about 38 hours battery storage that can operate the RO unit continually after the sunset . The RO systems powered by PV panels have many advantages, such as lowest operation cost , simple operation , environmentally friendly , easy installation and maintenance, high reliability and suitability for brackish water. the difference between the two projects is this paper using TRNSYST16 and PVRO Ain Shraish used WAVE and SAM software.

3. Chapter three

3.1 Source of water in Palestine

There are two main sources of the water in Palestine the surface water and the ground water, rainwater is the feed source for these sources, where the mean annual rainfall in the West Bank varies from about 700 mm in the western part to less than 100 mm in the east; the long-term annual average is about 450 mm[11]

3.1.1 Ground water

Groundwater is the main source of water for the Palestinians in the West Bank and Gaza Strip, providing more than 90% of fresh water supply for various purposes

It is typically divided into three sub-aquifers. The primary one, the Western Aquifer, this is the largest basin and the most important one among the West Bank Aquifer basins. It has a sustainable yield estimated at 362-400 million cubic meters per year. However, this basin is heavily exploited by the Israelis at variable rates of 340 -430 million cubic meters. In some years it reaches more than 520 million cubic meters, while the Palestinians consume only 28 million cubic meters through wells. The second one, the Northern Aquifer, most of the recharge areas of this basin are located within the West Bank boundaries and it has an annual sustainable yield of 100-145 million cubic meters. Despite this, the Israelis exploit the aquifer at a rate of 103 million cubic meters per year[12].

Finally, the Eastern Aquifer, the annual sustainable yield of this basin is estimated at 145 - 185 million cubic meters. However, the Israelis exploit the aquifer at a rate of 50 from wells in addition to 100 million cubic meters per year from Dead Sea Springs that are controlled by Israel; while the Palestinians utilized about 53 million cubic meters per year by wells and springs.

3.1.2 Springs and wells

The total number of the Palestinian wells in the West Bank tapping all aquifer systems is 383, of which 119 wells are not pumping or abandoned and in need for rehabilitation. The total annual abstraction from these wells is approximately 64 million cubic meters of which 36 million cubic meters for domestic use and 28 million cubic meters for agricultural use.

In addition to well abstraction, there are many springs that discharge water from the three-groundwater system of the West Bank. There are about 300 main springs emerging from different aquifers in the Eastern Basin and North-eastern Basin; most of them are small springs with an average discharge of less than 0.1 liter/second. The long-term annual discharge of these springs is around 54 million cubic meters[12].

3.2 Current water sources in Nablus, Palestine

Groundwater is the main source of water for Nablus city, its camps, and the neighboring villages that supply water from Nablus Municipality sources. Water is pumped from five underground wells owned by the Municipality of Nablus, in addition to five main springs within the city limits. Part of the needs of Nablus are pumped from wells run by the Palestinian Water Authority, and private wells located in the Al-Far'a area[13]. The amount of water pumped to the population at the end of 2018 was about 11 million cubic meters:

Al-Badan Well No. 1 : The well was drilled in 1969 in the lands of Talouza, northeast of Nablus, about 11km from the city center, at a depth of about 750m. The productivity of the well is 220m³/h. In 1971, the Municipality of Nablus extended a water line between the well and the city of Nablus with a diameter of 7.5 inches and a length of 7.5 km. In addition to Nablus, this well provides the villages of al-Badan, Talouza, and Asira Al-Shamaliya.

Al-Fara'a or Al-Badan No. 2 : Located to the northeast of Nablus city in Talouza, about 15km from the center of Nablus city, and 3.5km east of Al-Badan No. 1, this well was drilled in 1980 at a depth of 413m below the surface level, its productivity is about 170m³/h, the water is pumped from the well to Al-Badan pumping station by a 12-inch diameter water pipeline, and then by pumps to the Ain-Dafna central reservoir in Nablus.

Dir-sharaf well : Dir-sharaf well is located within the boundaries of Dir-sharaf village, tens of meters away from the main road connecting Nablus to Tulkarm. The well was drilled in 1994 at a depth of 670m below the surface of the earth, and its productivity is about 150m³/h, water is pumped from the well to Nablus through a 12-inch wrought iron conveyor line, which was implemented in 2008 as part of the waste reduction project. Dir-sharaf village is supplied from the well by a separate 4-inch water line.

Oudla Well : The well is located south of Nablus city between the villages of Huwwara and Oudla, at an altitude of 510m above sea level. This well was drilled in 1997; the excavation lasted from 18 March to 22 May due to the joint efforts of the German Corporation for International Cooperation (GIZ) and Nablus municipality, which produces 220m³/h, the water is pumped from Oudla well to Ain-Dafna reservoir through a 12-inch water pipeline, on the road between Oudla and Nablus, Iraq-Burin and Kafr-Qalil are supplied with water from Oudla well.

Sebastia well (Nablus 2) : Sebastia well is one of the most important sources of water for the city of Nablus and around it, where the productivity of the well reaches 300m³/h (2.7 million m³/year), which is equivalent to one fifth of the needs of the current population of Nablus City and around it estimated 30,000m³/day, or 11 million m³/year, was drilled in 2008, the Municipality of Nablus was not allowed to drill any new wells afterward and so far, the well is located to the northwest of Nablus city in Bourqa (Al-Mas'udia) basins at a depth of 750meters below the ground level, pumping water from the well toward Dir-sharaf. There are push pumps that pump the water of Sebastia and Dir-sharaf wells toward the city of Nablus. The well is also led by the Services Development Board northwest of Nablus, which includes Sebastia, Beit-Imrin, Naqoura, Nisf-Jbeel and Ijensnya.

During the summer, groundwater wells work almost non-stop. In winter, and spring season depending on the amount of rain, some wells are shut down due to increased spring productivity.

Al-Qaryoun spring: Al-Qaryoun spring is located in Al-Qaryoun neighborhood, in the heart of Nablus city, and the most beautiful neighborhoods of the Old City. Throughout history, the village of Qaryoun has been known for its abundance, and its momentum is almost as sweet as any other spring. The water flows from the depths of Mount Gerizim through paths that pass beneath the mosques, residences and alleys of the Old City, it emerges from the confluence of the slippery slope of Mount Gerizim to flat ground south of the Al-Nasr Mosque. Thus, since ancient times, many ancient Roman buildings surround the source of this spring; the spring of the village of water in the winter flow rate exceeds the rate of several deep artesian wells. Al- Qaryoun means the flowing spring in Syriac language, and there is archaeological evidence to show that Al- Qaryoun spring was feeding the Roman aqueducts that delivered water to the newly discovered Roman Column Street under Thafir Al-masri sahool. It was the flow and freshness of Al-Qaryoun spring that prompted the Romans to rebuild Nablus around this spring.

Ras Al-Ain Spring: Ras Al-Ain is located in the southern part of Nablus. An ancient fortress adjacent to the spring called Ras al-Ain Castle was built to be the protector of the city from the south, the entrance of the spring is located near the main street of Mount Gerizim on a hill known throughout history as the Hill of Helou, which had a good number of farms and fruits.

Ain-Dafna: From the eastern side of Mount Gerizim, and in the vicinity of the governorate building, about 200 meters southwest of the Dafna pumping station, the flow of Ain-Dafna water comes from the works of Mount Gerizim, filled with the smell of Islamic, Roman, and Canaanite civilizations, where it is historically considered that Ain-Dafna is the main source of water for the city of Nablus, and the oldest through the ages, because Ain-Dafna was connected to the "Shechem" Canaanite, and Nablus Roman through tunnels and water channels carved rock underground, and most of them still exist, and these tunnels highlight different points of wells on the east side of the old town where it was the main estuary of Ain Dafna.

Ein al-Asal: The spring of Ein al-Asal, and Al- Qaryoun spring, have formed a nerve in the lives of the people of Nablus for thousands of years. The same applies to the spring of Ras Al-Ain, which includes buildings, infrastructure and a beautiful architectural structure. The Turks took care of this spring and linked it with many ways to supply passers-by and residents with albumin water, as well as to supply the city's orchards.

Ein Beit Al-Maa : Ein Beit Al-Maa spring is located on the main road leading to Tulkarm and the spring is connected by canals extending down the site of Ein Beit Al-Maa refugee camp, where infrastructure is weak, making it constantly vulnerable to pollution. Ein Beit al-Maa is the most flowing of the Nablus springs outside the Old City, and has had less luck in the literature of travelers and scientists, but hydro logically, it is very important to supply water to Nablus residents. Its hydrogeology is more complex than the other springs of Nablus, due to its proximity to Mount Ebal and a little further to Mount Gerizim. Ein Beit Al-Maa feeds mainly from Mount Gerizim, and may have been fed from other areas of Mount Ebal.

Until 1934, the city of Nablus relied entirely on the fountains of Al- Qaryoun, Ain al-Asal, and Ras Al-Ain where water was transported through mud pipes to various water routes, which are located throughout the Old City, and from these ways residents used to get water for their homes, And their shops by their own means using special pots and donkeys.

However, the municipality decided at that time to build a water distribution network in order to efficiently distribute water and avoid contamination. Accordingly, the municipality issued laws enabling it to own the three springs (Al- Qaryoun, Ain al-Asal, Ras al-Ain). Residents with access and title to these springs were provided with free quantities of water, and were granted on the basis of Quotas and shares.

In addition to the sources that mentioned in Nablus City there is a lot of wells that suffers from pollution water problems which can be treatment and get fresh water from it, for example Ain Sharish.

3.3 Ain Sharish

Ain-Sharish is one of most proper well for desalination, water source for Ain Sharish is extends from wells in the Old City to Dulab wells in Qayasra alley and it pass through Zafer Al-Masri School and Bab Al-Saha then to Al-Hammouz Café. Ain-Sharish Water is Polluted and not drinkable water because it has a high pollution rate but it used for agriculture and gardens, also they used 50 cubic meters of the water for reserve tanks in Jamal Abd Al-Nasser Park to drainage sewage from the city and sometimes for concrete companies. Moreover, it

has a production capacity of 70 cubic meters per hour through the wells in the winter and if the rainfall was heavy it produces more than this. On other hand, in the summer the production capacity is 10-15 cubic meters per hour[14]. In addition the water of Ain Shraish contains a pretty good amount of containment as Potassium and Fecal which are exist in very high ratio because of that water used only for agriculture and industrial service, Reverse Osmosis (RO) System removes contaminants from water by using high pressure to obtain fresh water which is able to use in residential service.

4. Chapter four

4.1 Classification of Desalination

The scarcity of freshwater resources and the need for additional water supplies is already critical in many arid regions of the world and will be increasingly important in the future. Many arid areas simply do not have freshwater resources in the form of surface water such as rivers and lakes. They may have only limited underground water resources, some that are becoming more brackish as extraction of water from the aquifers continues. Solar desalination evaporation is used by nature to produce rain, which is the main source of freshwater on earth. Desalination is the common alternative to obtain fresh water.

Desalination: from the root word desalt meaning to “remove salt from”. By convention, the term desalination is defined as the “process of removing dissolved solids, such as salts and minerals, from water”. Other terms that are sometimes used interchangeably with desalination are desalting and desalinization, although these terms have alternate meanings; desalting is conventionally used to mean removing salt from other more valuable products such as food, pharmaceuticals, and oil, while desalinization is used to mean removing salt from soil, such as by leaching.

Water desalination processes separate dissolved salts and other minerals from water. Feed water sources may include brackish, seawater, wells, surface (rivers and streams), wastewater, and industrial feed and process waters. Membrane separation requires driving forces including pressure (applied and vapor), electric potential, and concentration to overcome natural osmotic pressures and effectively force water through membrane processes. Distillation is the process of heating water to the point of evaporation (leaving contaminants behind), then condensing that steam into pure water. It is a simple one-step, physical process - the same process that nature uses - that generates reliable high-quality water every time. Our products remove contaminants, use no chemicals or other disposables, operate close to maintenance free, and require no custom engineering to accommodate different contaminants in the water. Figure 4-1 clarify the classification of desalination processes.

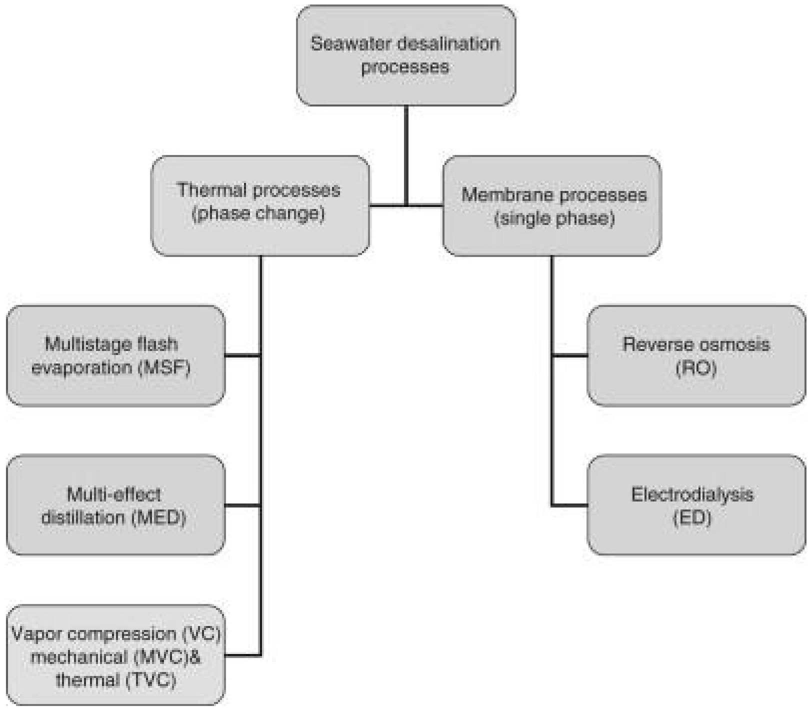


Figure 41 Classification of Desalination

4.2 Distillation Processes

Distillation is the process to raise the temperature of the salt water to the boiling point, and the composition of water vapor, which is then condensed into distilled water that is free from salt; it is then treated with additives to be drinkable or irrigation water. This technique is often used for industrial, chemical and bio-applications. Whereas thermal desalination accounted for 27% of global installed capacity, corresponding to about 24 million m3/day of fresh water produced. Most Gulf Countries, including Saudi Arabia, UAE, Oman, Bahrain, Kuwait, Qatar, and other countries, notably Israel, Egypt, China, Iran, Algeria, Libya, still choose thermal desalination as total or partial fresh water source. Distillation has four types which is multiple stage flash evaporation (MSF), multiple-Effect Distillation (MED) and Vapor Compression Distillation (VC).

4.2.1 The multiple stage flash - Evaporation (MSF)

In the process of multi stage flash desalination, the fresh water is separated from brine by evaporation, where MSF plants normally reach and exceed 20 stages, before the first stage, the brine water heated until up the first inlet temperature value in a heater powered by hot steam from a steam generator. In addition, integrated brine repeaters are put on top of each flash evaporator to slightly increase the brine temperature before it flows into the heater. Depending on the fact that the boiling point of the liquid is directly proportional to the pressure on it, the less pressure on the liquid, the lower the boiling point. In this way, the remaining water in the heater after heating is transferred to successive low-pressure chambers where the pressure in each chamber is less than the pressure in the previous chamber. Once brine enters the stage, its temperature drops to the saturation temperature at that pressure and turns it into vapor. And it is converted into steam and then to distilled water, which is collected and treated for drinking water and other uses.

Very large facilities and investments are typical of this technology, which is considered to be the most reliable and widely used in the Middle East and elsewhere, in order to provide water needs for both the residential and industrial sectors. Multi-stage flash distillation plants account for about 20% of desalinated water production worldwide, the current water supply market still places thermal processes second right after reverse osmosis in the list of commercial ways to get fresh water from salt water. The principle is illustrated in Figure 4-2.

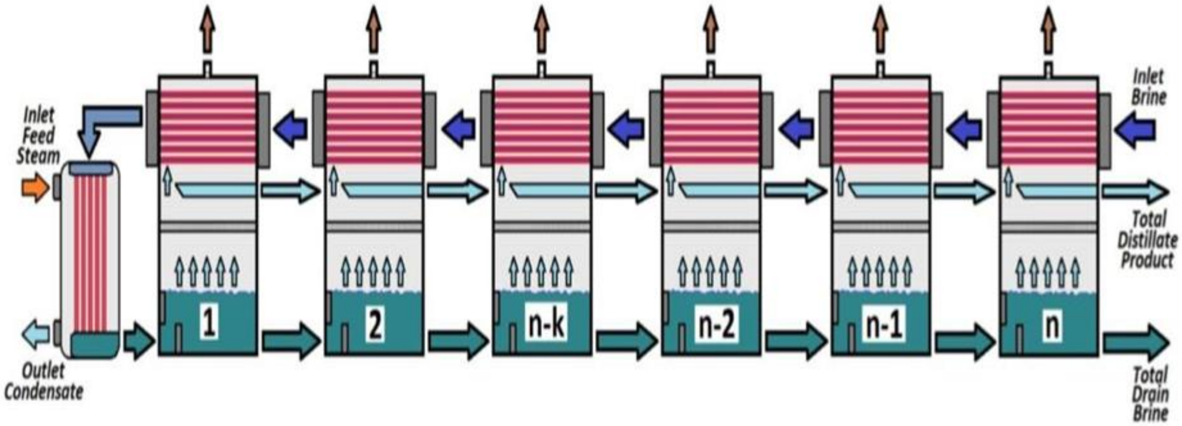
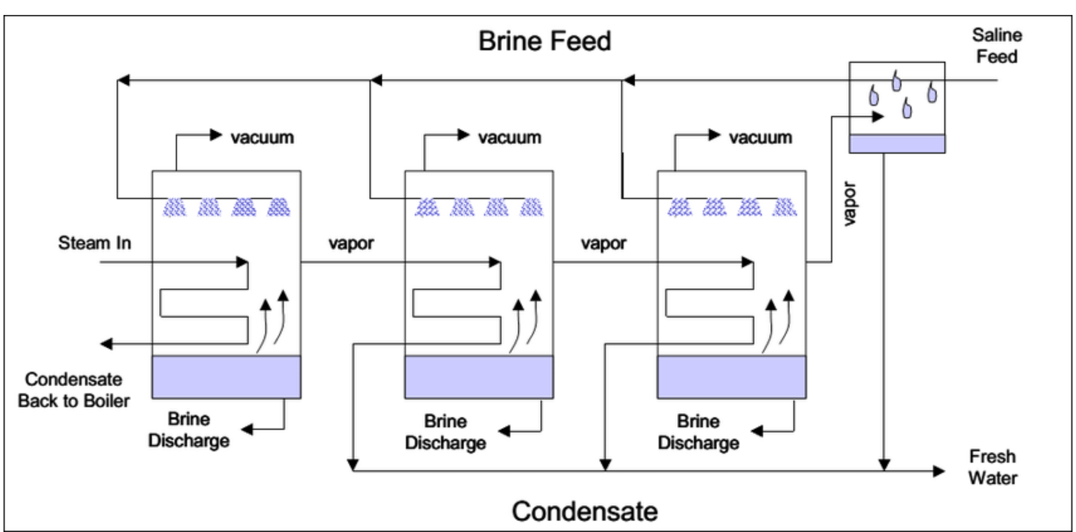


Figure 42 principle of desalination processes

4.2.2 The Multiple Effect Distillation (MED)

Multi effect distillation (MED) is in principle similar to multi stage evaporation, but in multi effect distillation the succeeding stage serves as condenser for the steam generated in the previous stage. Thereby the first stage is supplied with energy from external sources, normally with heating steam from a boiler or waste steam from a steam turbine.

MED desalination plants are composed of a variable sequence of stages, ordinarily from 5 to 10. The seawater enters from the top of the effect, and falls on the tubes surface that are heated by steam from a boiler, or other source. On the pipes surface, the brine film absorbs the condensation enthalpy of the vapor flowing inside, and part of it evaporates according to thin film evaporation. The vapor produced is filtered by means of a demister, and exits the effect. The remaining feed water is fed to the second effect. Only a portion of the seawater applied to the tubes in the first effect is evaporated. Where is again applied to a tube bundle. These pipes are in turn being heated by the vapor created in the first effect, then this vapor is condensed to fresh water, while giving up heat to evaporate the remaining seawater feed in the next effect.



Vapor compression is a reliable and sturdy desalination technology, that is attractive because of its capacity to treat huge amount of water with a wide range of salt concentrations through the use of developed vapor compression technology, where the heat for evaporating the water comes from the compression of vapor instead of the direct exchange of heat from steam produced in a boiler. This process is generally used in combination with other processes such as multi effect desalination to improve overall efficiency. And there are two (VC) processes:

The Mechanical Vapor Compression (MVC):

The Mechanical Vapor Compression is the most efficient distillation process, in which a mechanical compressor is used. The compressor creates a vacuum in the vessel and then compresses the vapor taken from the vessel and condenses it inside of a tube bundle also in the same vessel. Seawater is sprayed on the outside of the heated tube bundle where it boils and partially evaporates, producing more vapor.

The Thermal Vapor Compression (TVC):

If steam at a relatively high temperature and pressure level is available then thermal vapor compression can be utilized to improve the efficiency of the seawater desalination plant Thermal vapor compression is an open process, the motive steam which comes from the boiler at high pressure and low velocity enters, and mixes with the suction steam, the mixture is fed into the first stage evaporator and appears after the condensation as liquid distillate. A part of this distillate returns to the boiler as boiler feed water, while the rest is added to the distillate of the remaining stages. The principle is illustrated in Figure 4-4.

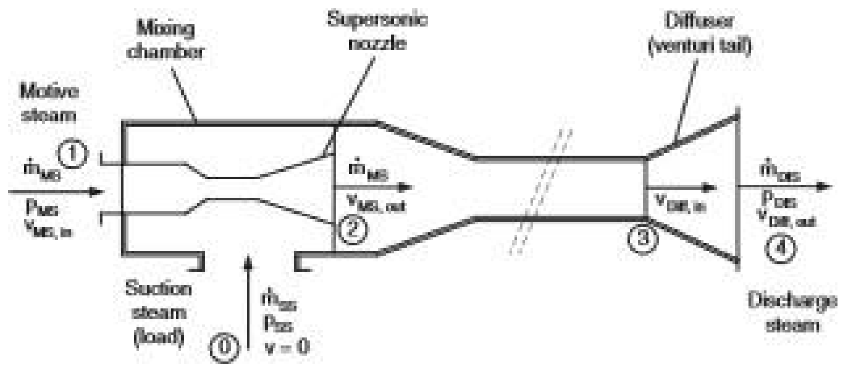


Figure 44 scheme of thermal vapor compression process

4.3 Membrane Desalination

Membranes are barriers that allow some things to pass through but stop others, Such as molecules, ions, impurities or other small particles. Membrane desalination uses membranes to separate fresh water from brine water. Feed water is passed through the membrane because of the pressure difference between one side of the membrane and the other, which selectively passes water and excludes salts and others Contaminants. Although many types of filtering methods are used for desalination, pressure driven membrane systems are the leading technology because of their ability to separate smaller substances from water.

The microstructure of a membrane is a critical subject, and is dependent on the preparation procedures. There are many ways to classify synthetic membranes. They can be classified by the membrane morphology, nature of the membrane material, preparation methods, geometry, separation processes etc. For example, synthetic membranes can be organic (polymeric) or inorganic (metal/ceramic), solid or liquid, electrically charged or neutral in nature, they can be homogeneous or heterogeneous, symmetric or asymmetric in structure. Grouped by membrane geometric shapes, synthetic membranes can be flat, tubular or hollow fiber membranes. Commonly, membranes are classified according to their morphology shown in figure 4-5 porous membranes, dense homogeneous polymer membranes, and composite membranes (thin film). The latter membranes are today widely used in brackish and sea water RO desalination.

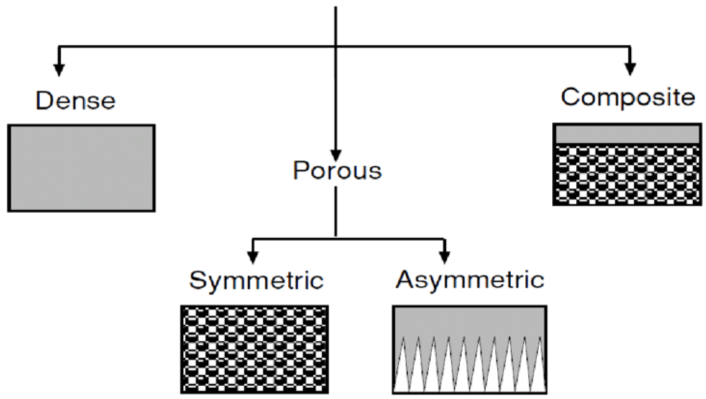


Figure 45 membrane classification based on morphology

Four widely used membrane separation processes in water desalination, namely, microfiltration (MF), ultrafiltration (UF), Nano filtration (NF), electrical dialysis and reverse osmosis (RO).

4.3.1 Microfiltration Membrane (MF)

Microfiltration Membrane is a type of physical filtration process, where contaminated water is passed through a special pore size of 100 to 10,000 nm perform microfiltration to separate microorganisms and suspended particles from liquid. Microfiltration can be implemented in many different water treatment processes when particles with a diameter greater than 0.1 mm need to be removed from a fluid.

4.3.2 Ultrafiltration Membrane (UF)

is a variety of membrane filtration in which forces like pressure or concentration gradients lead to a separation through a semipermeable membrane. The pores of ultrafiltration membranes can remove particles of 2 to 100 nm from fluids. It concentrates suspended solids and solutes of high molecular weight, while water and low molecular weight solutes pass through the membrane in the permeate. This separation process is used in the fractionation of milk, whey, and also finds in industry and research for purifying and concentrating macromolecular solutions, especially protein solutions. Ultrafiltration is not fundamentally different from microfiltration, Both of these separate based on size exclusion or particle capture.

4.3.3 Nano filtration Membrane (NF).

Nano filtration Membrane is a relatively recent membrane filtration process used often with low total dissolved solids water such as surface water and fresh groundwater. It is use partially permeable membranes to separate different fluids or ions, and remove particles from approximately 0.5 to 2 nm. It concentrates organic solutes, suspended solids, and polyvalent ions, while the permeate contains low molecular weight organic solutions and monovalent ions.

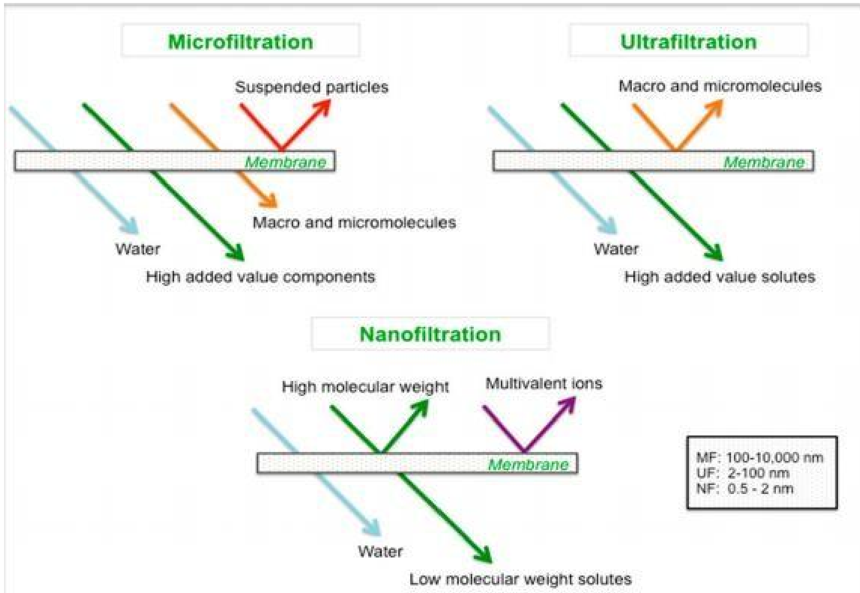


Figure 46 Nano Filtration Membrane

4.3.4 Electro Dialysis (ED)

As illustrated in Figure 4-7 an ED is an electrochemical process used to transport salt ions from one solution across charged membranes to another solution under the influence of an electrical potential difference used as a driving force. This is done in a configuration called an electro dialysis cell, the cell consists of a series of anion and cation exchange membranes are arranged in an alternating pattern between an anode and a cathode to form individual cells. This process has been widely used for treatment water from brackish water, recovery of useful materials from effluents, treatment of industrial effluents, and salt production.

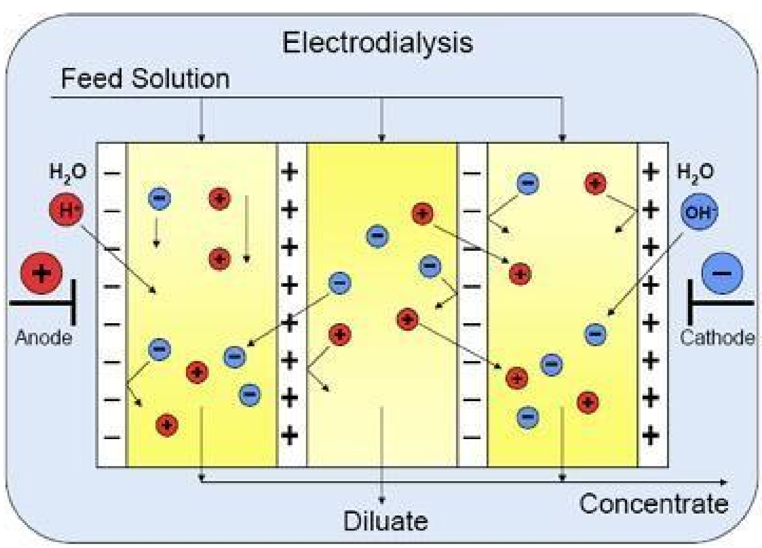


Figure 47 Schematic view of an ED cell

4.3.5 Reverse Osmosis Process.

Osmosis is the process of solvent passage through semipermeable membrane whereas the lower concentrate solvent will be filtered to higher concentrate solution. The osmosis pressure happens to move the molecules of solution. However, if the process is reversed, and the higher concentrate solvent moves toward lower concentrate solution, then reverse osmosis happens.

Reverse osmosis is one of desalination processes that is used in many applications such as recycling, wastewater treatment, and energy production. In this procedure, saltwater will be in a side of the tank and pure water in another side, the barrier is semipermeable membrane. The pressure applied to the saltwater will be more than osmotic pressure on pure water to push saltwater through the membrane (See figure 4-8).

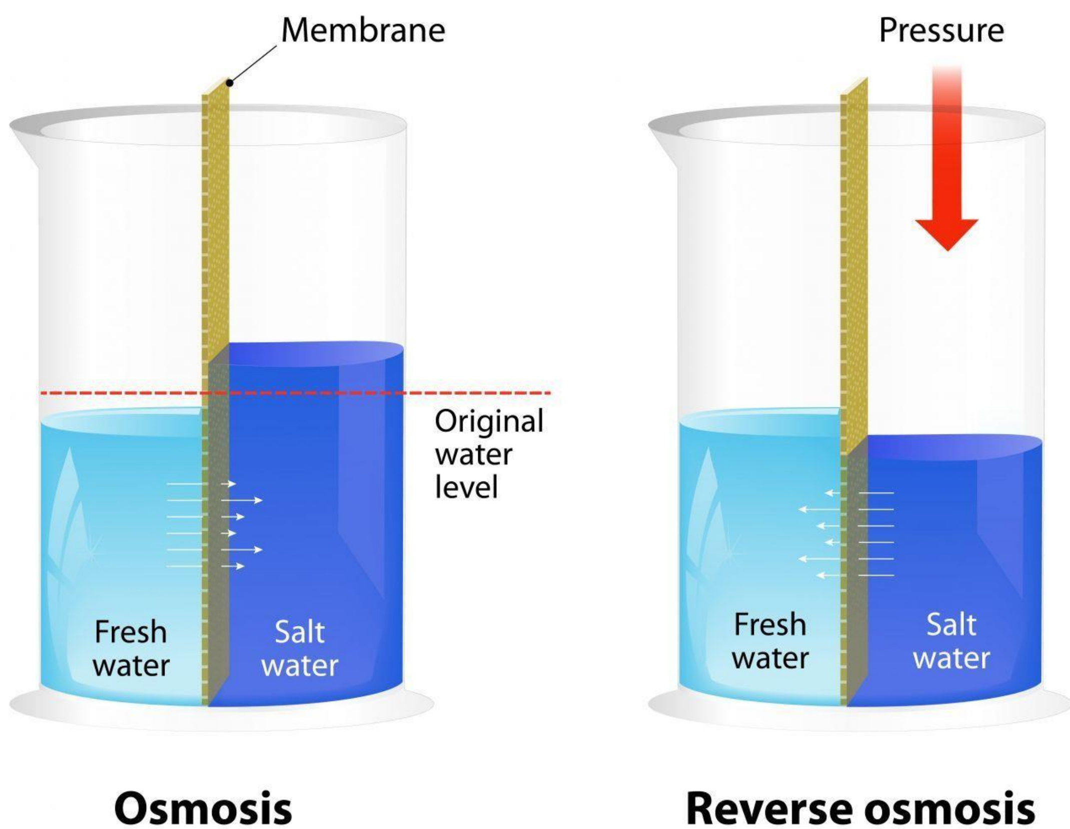


Figure 4‑8 Osmosis and Reverse Osmosis phenomenon.

The desalinated water that is produced by reverse osmosis called permeate water, and the contaminants that did not pass through the membrane called reject (or concentrate) stream (see figure 4-9).

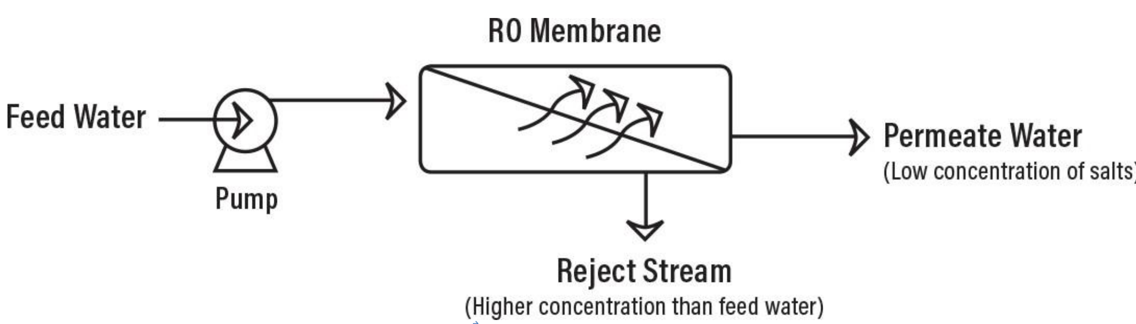


Figure 4‑9 Flow chart of reverse osmosis system

In order to obtain proper operation for reverse osmosis system, there are main four components should be available in the system which are:

- Pretreatment system
- high-pressure pump
- membrane assembly
- post-treatment system

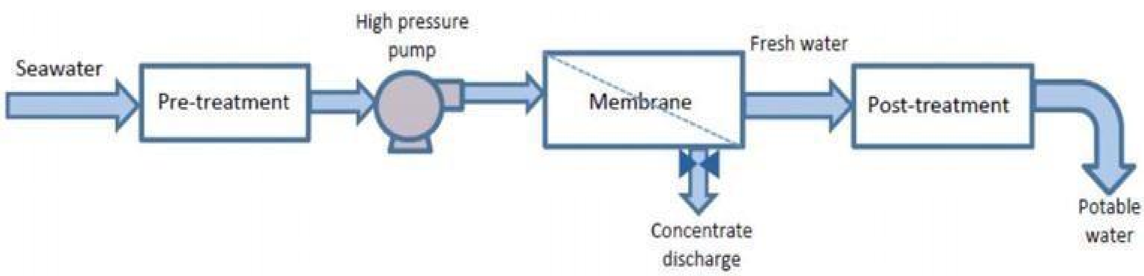


Figure 410 reverse osmosis process

First of all, pretreatment system for feed water is vital in all desalination technologies including reverse osmosis system. In addition, the need of this step depends on many parameters such as feed water composition, the Recovery from the system or unit and the Solubility for certain salts. This process aims to remove suspended solids to prevent or control sediment also to clean and sterilize feed water. The next step is using High Pressure Pump in order to increase the pressure for feed water before treatment or entering membrane assembly steps to break through membranes and get over the difference of osmosis pressure in the water used, the required pressure depends on the concentration and the temperature of feed water whereas increasing of concentration increases the osmotic pressure and therefore, the required operation pressure should exceed the opposite osmotic pressure for the reject solution in outlet of membranes. moreover, the membrane is made from Cellular Acetate and Polyimides, the most common pattern of membranes are spiral wound, hollow fine fiber module, tubular module membrane also plate and frame module that will be mentioned later. Finally, the produced water from Reverse osmosis unit needs treatment before send it to storage tanks and consumers, this process is very important because the produced water may cause danger corrosion problems for tanks also transmission and distribution pipes grid.

The performance of RO system depends on the type and module of membrane; the four main modules

Membrane modules:

There are four types of membrane modules commercially available, as follows:

1.Plate and Frame

2.Spiral-wound

3.Hollow-fiber

4.Tubular

So:

1- Plate and frame module: As figure 4-11 illustrates, this type of modules uses membranes with flat plates that are placed between gaps and supports, supports are also formed flow channel for flowing water, feed water flows through the flat plates and form one layer. The maintenance of this type of membrane is possible because of the nature of its assembly, and this type of membranes can reach high recovery through the long feed channels used to control the feed streams, which often cause problems and damage to the membranes

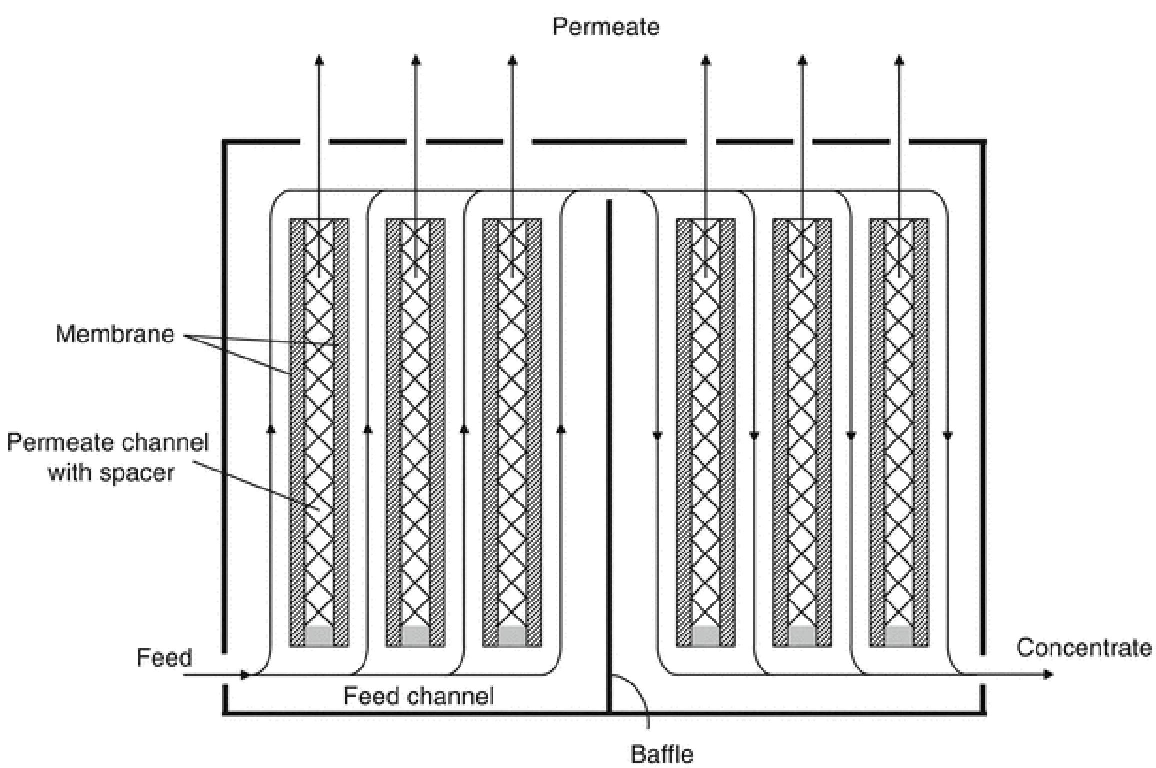


Figure 4-10 plate and frame module

2. Spiral-wound module uses flat, spirally wrapped laminated membranes and spiral stents are wrapped around a central tube (figure 4-12), feeding flows pass from the end of the spiral coil and parallel to the coiled membrane. The supporting layers are designed to reduce pressure drop and allow increased loading density on the membranes.

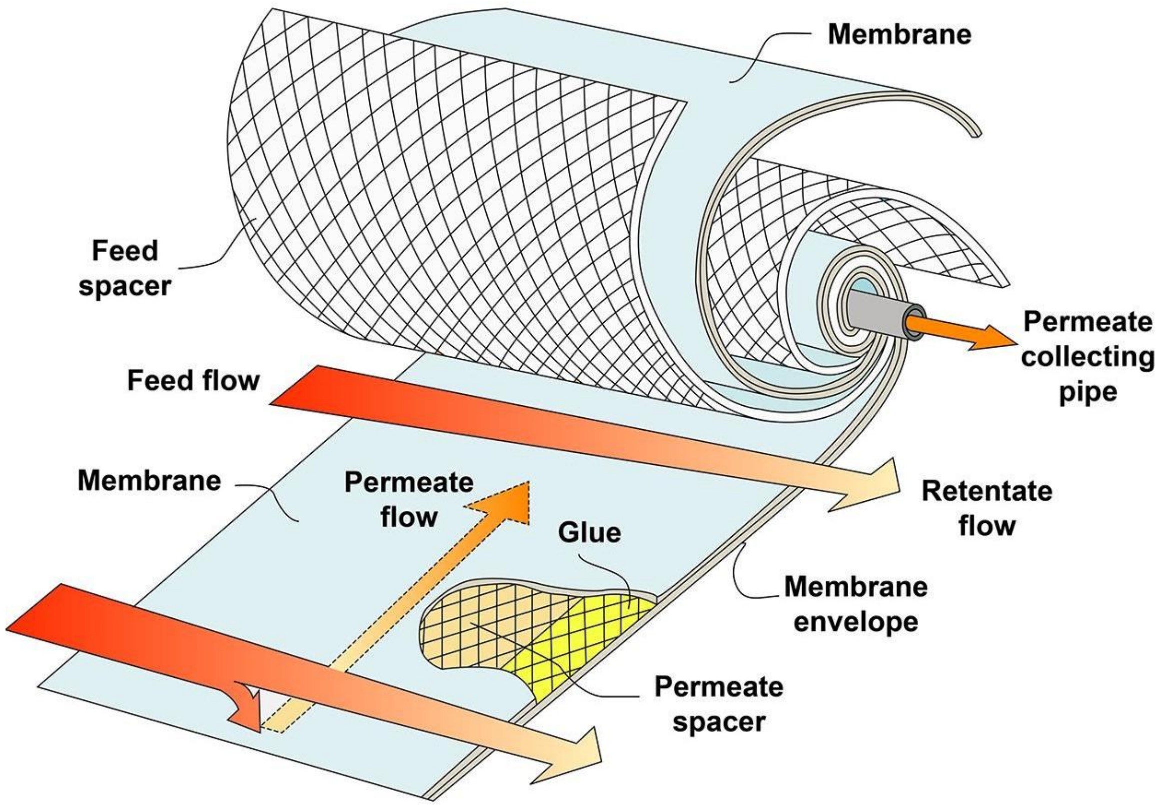


Figure 412 Spiral wound module

3. Hollow fiber module: as figure 4-13 illustrates hollow fibers that is consisting of membrane fiber bundles of small diameter inside cylindrical pressure vessels, the fibers are adapted to the pressure from the outside, the flow is through the inner holes of the hollow fibers down below the fiber until it reaches the main part of the fiber at the bottom of it These hollow fibers can also adapt to atmospheric pressure from the inside, but greater mechanical durability of fibers is essential to prevent rupture of these fibers.

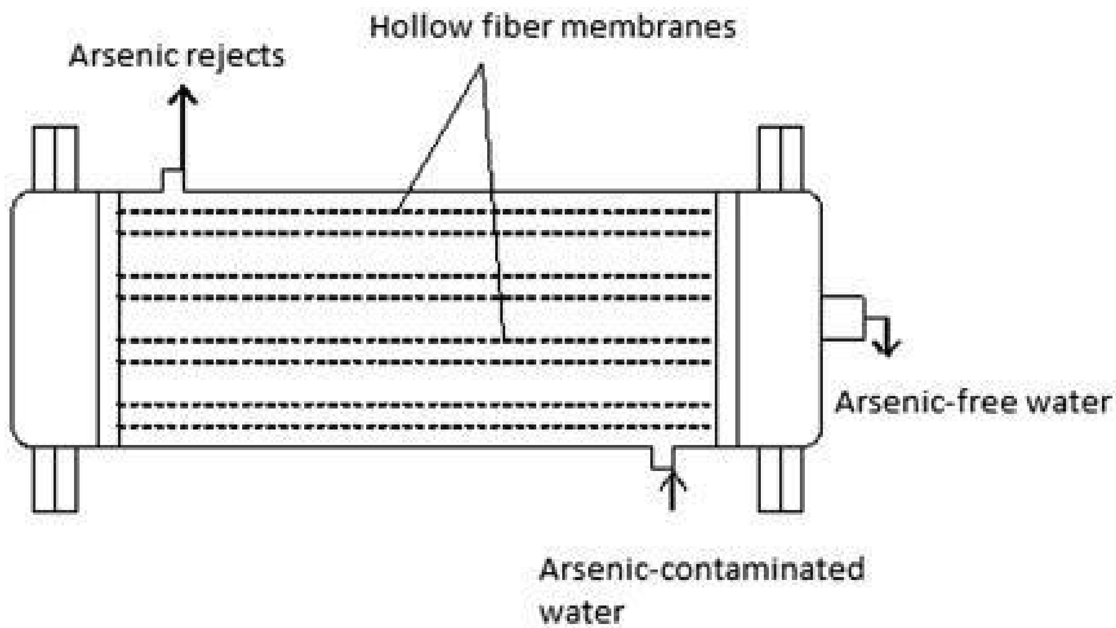


Figure 413 Hollow fiber module

4. Tubular module:

Tubular modules have supported from the inside of a pipe, where the operator can easily repair feed water channels and outlet water in order to remove contaminated or food spoilage layers. These modules are somewhat resistant to damage when operated by turbulent (discontinuous) feed flows, which is linked to flow channels that are larger than those used in the hollow fiber module and the spiral-wrapped membrane module.

The Problem of using this module compared to the previous two modules are:

-High capacity needs to pump very large volumes of feed water

-High cost of capital

-Low area of membrane (effective) per unit volume of water prepared for treatment; figure (4-15) illustrates this type of model:

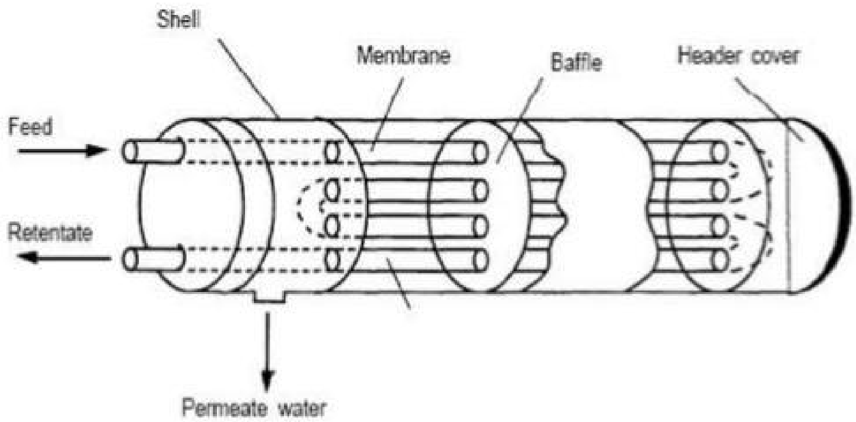


Figure 414 Tubular module

Table 41 Comparing between all Technologies [15]

4.4 Comparing between all technologies

Desalination Process	MSF	MED	VC	RO	ED
Energy Consumption kWh/m3	Steam and power consumption. (3-5 kWh/m3)	Steam Consumption. (1-2 kWh/m3)	Steam consumption. (8-12 kWh/m3)	Power Consumption. (3-6 kWh/m3)	Power consumption. (0.8-1.5 kWh/m3)
Advantages	MSF plants especially large ones, produce a lot of waste heat and can therefore often be paired with cogeneration.	Good salt-water separation effect, high automation, and stable operation.	technique copes well with high salt content in water.	high technical maturity, small land occupation, and high-water quality.	low investment, small land occupation, long service life of membrane and simple operation.
Disadvantages	high operating costs when waste heat is not available for distillation and high rates of corrosion.	high investment, easy for scale formation and corrosion, large land occupation and high steam consumption.	High steam consumption.	high investment, frequent cleaning of membrane, and high requirement of inlet water.	low desalination rate, high power consumption, and easy for scale formation due to polarization.
Applicable Salinity	High salinity.	Relatively high salinity.	High salinity.	Medium and low salinity.	Medium salinity.

5. Chapter Five

5.1 Solar Energy and Photovoltaic Cell

The sun is the most abundant renewable energy available on the planet. The amount of energy that earth receives from the sun is enormous. Solar energy is energy from the sun that is converted into thermal or electrical energy, it is the cleanest and most renewable energy source available. Solar technologies can utilize this energy for a variety of uses, including generating electricity and providing a comfortable interior environment. Photovoltaic cells are an integral part of solar-electric energy systems, which are becoming increasingly important as alternative sources of utility power.

5.1.1 Solar Radiation

Solar radiations are becoming increasingly appreciated because of their influence on living matter and the feasibility of its application for useful purposes. It is a perpetual source of natural energy that, along with other forms of renewable energy, has a great potential for a wide variety of applications because it is abundant and accessible.

Palestine has one of the highest solar potentials of all the countries of the world. It enjoys over 2800 sunshine hours every year, with an annual average daily solar radiation intenstiny amounting to 5.4 killoWatt hour per meter cubic per day.

In Table 5-1 it shows the avareage global radiation during year 2018 in all months.

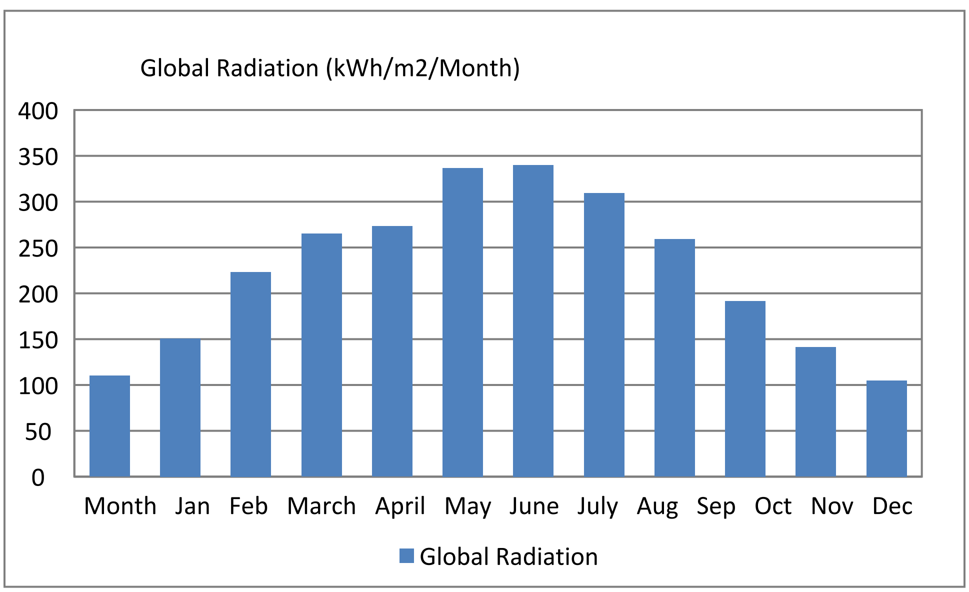


Figure 51 Average Global Radiation per Months

5.1.2 Solar Cell

An individual photovoltaic cell produces an Open circuit voltage(VOC) of about 0.5 to 0.6 volts at 25 °C ,no matter how large they are. This cell voltage remains constant just as long as there is sufficient irradiance light as illustrated in figure below . Open circuit voltage means that the PV cell is not connected to any external load and is therefore not producing any current flow. When connected to an external load, the output voltage of the individual cell drops to about 0.46 volts as the electrical current begins to flow, and will remain around this voltage level regardless on the sun's intensity. This decrease in output voltage is caused by resistance and power losses within the cells structure as well as the metallic conductors deposited on the cells surface. Temperature also affects a photovoltaics output voltage. The higher the temperature is, the lower the cell's output voltage becomes as the cell degrades under the hot conditions.

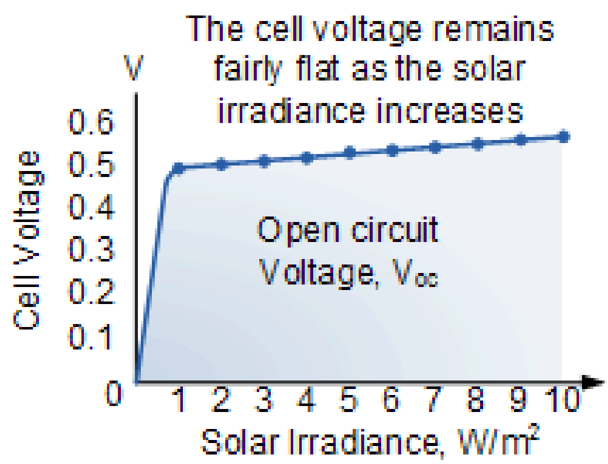


Figure 52 relationship between solar irradiance and cell voltage

Unlike a photovoltaic cells voltage, the output DC current .however, does vary in direct relationship to the amount or intensity of the sunlight falling onto the face of the PV cell. Also the output current is directly proportional to the cells surface area as the larger the cell the more light energy enters the cell. Then the more sunlight entering the cell, the more current it produces. Photovoltaic cells with high current outputs are generally more desirable, but the higher the current output, the more they will cost.And the figure below shows the relationship between cell current and load resistance .

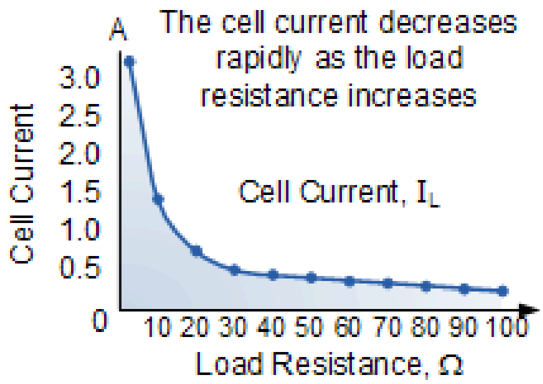


Figure 53 relationship between cell current and load resistance

5.1.3 Photovoltaic Operating Principle

A photovoltaic cell (PV) consists of many layers of material, each with a specific purpose. The most important layer of the photovoltaic cell is the semiconductor layer.It is comprised of two layers,one layer has a positive charge(p-type), the other negative(n-type),and is what converts the Sun's energy into electricity through a process called the photovoltaic effect.

The photovoltaic effect is a process that generates voltage or electric current in a PV cell when it is exposed to sunlight. In a PV cell, flat pieces of semiconductor materials are placed together, and the physical boundary between them is called the P-N junction , an electric field is formed in the region of the junction as electrons transfer to the positive side and holes move to the negative side.This field causes positively charged particles to move in one direction and negatively charged particles in the other direction. Light is comprised of photons, which are a small bundles of electromagnetic radiation.When light of a suitable wavelength is incident on these cells, energy from the photon is moved to an electron of the semiconducting material, causing it to jump to a higher energy level known as the conduction band. In their state in the conduction band, these electrons are free to move through the material, and it is this motion creates an electric current in the cell.

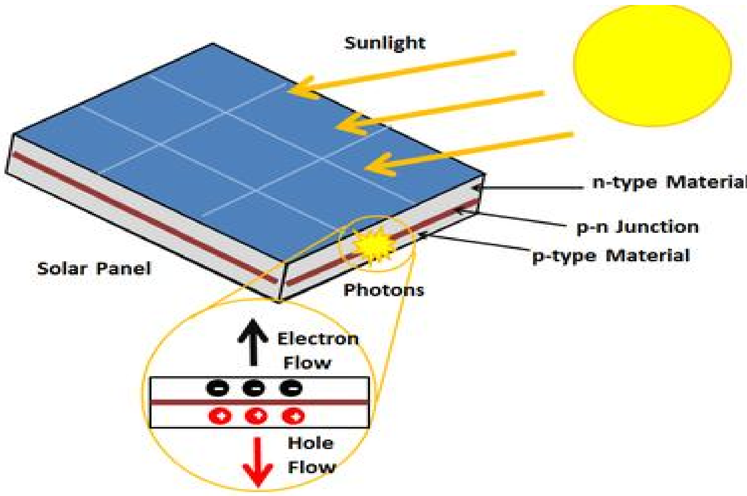


Figure 54 A diagram showing the photovoltaic effect

5.2 Types of Photovoltaic Cell

5.2.1 Mono Crystalline Silicon Cell

Generally, monocrystalline silicon solar PV is the best technology to deliver efficiency,where ranging between(16% - 22%). It is made by growing a single crystal,monocrystalline panels are cut into the distinctive patterns that give them their recognizable appearance. The crystal framework in a monocrystalline is even, producing a steady blue color and no grain marks, giving it the best purity and highest efficiency levels.

5.2.2 Poly Crystalline Cell

Polycrystalline solar is made by pouring molten silicon into a cast. However, because of this construction method, the crystal structure will form imperfectly, creating boundaries where the crystal formation breaks. This gives the polycrystalline silicon its distinctive, grainy appearance, as the gemstone type pattern highlights the boundaries in the crystal.Because of these impurities in the crystal, polycrystalline silicon is less efficient (13% -19%) when compared with monocrystalline. However, this manufacturing process uses less energy and materials, giving it a significant cost advantage over monocrystalline silicon.

5.2.3 Thin Film Cells

The technology with the lowest market share is thin-film, but while it has several disadvantages, it is a good option for projects with lesser power requirements.It can be constructed from a variety of materials. As a technology that’s still emerging, thin-film cells have the potential to be less expensive,and its efficiency is estimated between(12% - 16%).

6. Chapter Six

6.1 Methodology

To design the proposed RO system powered by PV for small scale such as houses, documentary data were collected from several governmental and nongovernmental organizations and institutions. The data were used to estimate the require amount of water also to estimate the amount of solar energy needed throughout the whole year, Ain-Shraish were chosen as a water source for the system.

The next figure is show the methodology to find if the DC pump is visible to work with direct coupling with solar power and given the needed water flow rate also shows the programs that used.

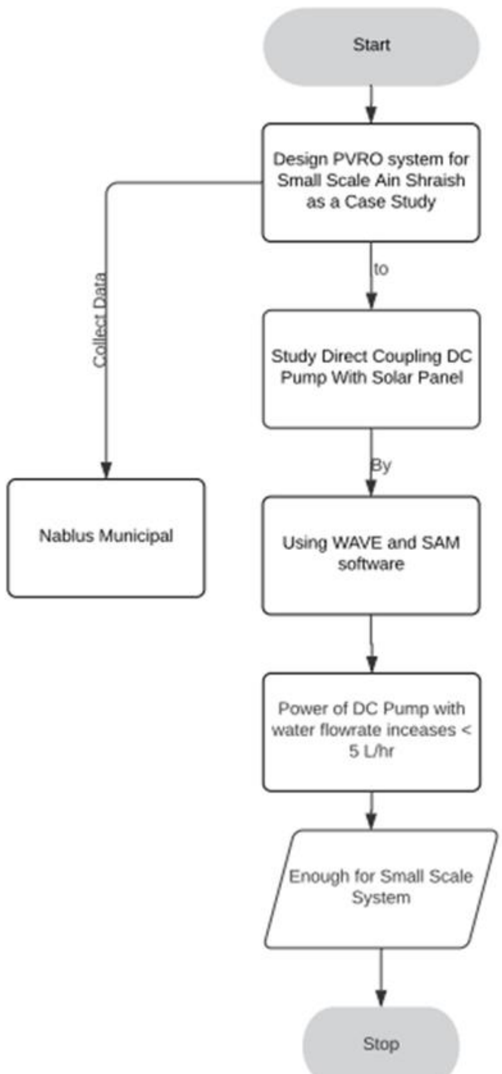


Figure 61 Methodology of the Project

6.1.1 Ain Shraish Location and Water Quality

Ain-Shraish located in the City of Nablus [32.222700, 35.257339], the spring is about 25 meters from Taxi Services (Garages for Villages), 368 meters from the city roundabout (Martyrs' Square roundabout) located in the city center, 80 meters from Al-Hamouz Café, and 112 meters from Nablus Municipality Library.

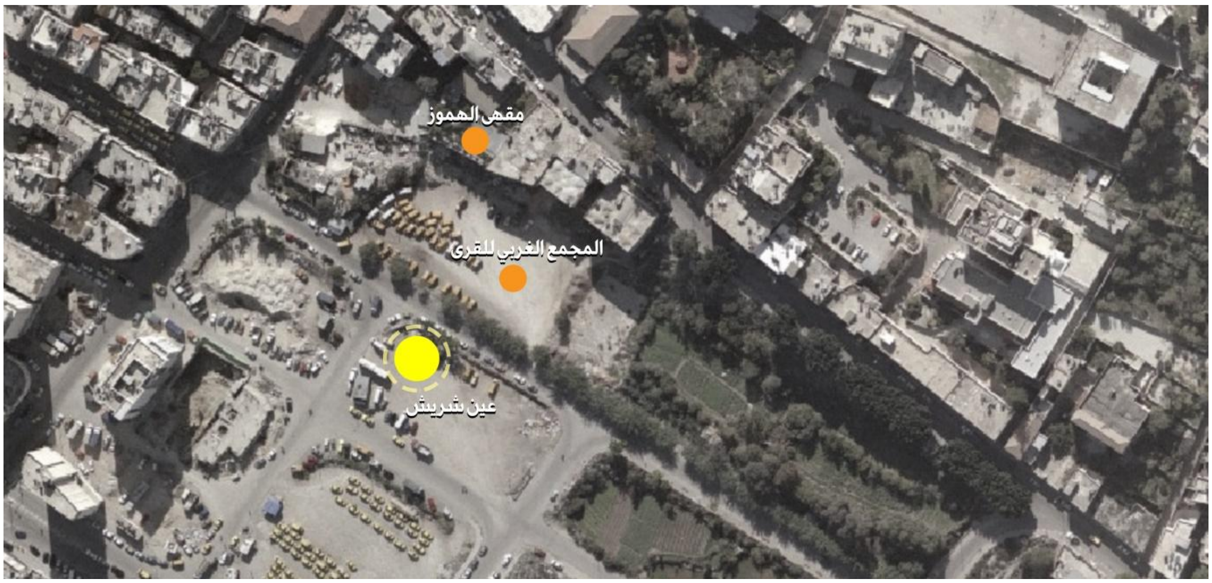


Figure 62 Ain Shraish Location using Geomolog

The table below shows the water quality of Ain Shraish, the amount of Potassium and Fecal are very high so they use the water only for agriculture and industrial service, Reverse Osmosis (RO) System removes contaminants from water by using high pressure to obtain fresh water which is able to use in residential service.

Table 61 Properties of Ain Shraish water [16]

PH	TDS (mg/L)	Fecal (cfu/100mL)	Turbidity (NTU)	K (mg/L)
7.62	397	600	0.26	30

After the RO process using solar power as energy source for DC pump the outlet drinking water must have standard properties

Table 62 the slandered properties for drinkable water

PH	TDS (mg/L)	Fecal (cfu/100mL)	Turbidity (NTU)	K (mg/L)
6.5-8.5	100-200	0	1-2	20<

6.1.2 System Components

PVRO system is a combination between two main units, desalination unit and power generation unit. PV power unit involves one PV panel produced DC power in certain period through the day, and RO desalination unit consists of RO membrane and high pressure pump. The feed water is pressed by pump to pass through the membrane which is reducing the concentration of the solute to produce the permeate and reject high salt concentration as brine.

6.1.3 System Design Parameters

For PV RO system, the system is running directly by the output of PV panel. In this section, the mathematical representation of the PV panel, pumps, and RO process will be discussed

6.1.3.1 Membrane Modeling

According to Palestinian Central Bureau of Statistics (PCBS)[15], the consumption amount of drinking water for Palestinian household is 21 Liters per day. This quantity of water needed to be produce which will be taken from Ain-Shraish spring which has a capacity of 70 cubic meters per hour in winter and about 10 to 15 cubic meters per hour in summer according to Nablus Municipality [16].

Permeate recovery is one of more important parameters in the design and operation of RO systems. Recovery or conversion rate of feed water to product (permeate) is defined by Equations 1 and 2 used to calculate the permeate recovery:

(1)

(2)

Where R is the permeate recovery, Q_p is the product water flow rate, Q_f is the feed water flow rate, and Q_c is the concentrate flow rate.

$$R = () = 70\% \quad (3)$$

Design Reverse Osmosis using WAVE software:

WAVE Software have been used to select the membrane according to some factors such as the flow rate of feed water, the recovery, and water type. Where the used membrane is ECO PLATINUM 440 which is Spiral-Wound element with polyamide thin-film composite membrane.

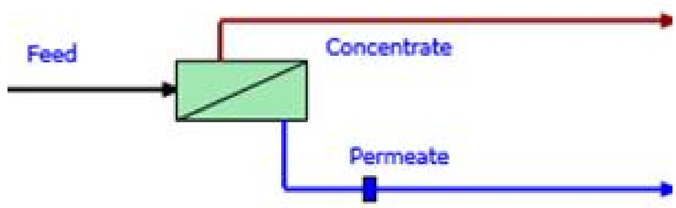


Table 63 Reverse Osmosis with one pass and one stage

RO process occurs through one stage and one pass, where selecting the number of stages depends on the recovery and the number of passes depends on the TDS of feed water. Table 4.4 shows the properties of the selective membrane

Table 64 Membrane Results from WAVE software

Results	**Value**
Number of elements	6
Feed pressure	1.5 bar
Flow Factor	0.85
Average Net Driven Pressure	0.1 bar
Product TDS	143.5 ppm
K_+	16.04 mg/L

Salt Rejection:

The salt rejection describes the quantity of salt removed from the reverse osmosis feed water stream as a percentage. And it is calculated by the equation below:

$$\% \text{ Salt rejection} = (1- \ ) \qquad (4)$$

Where the salt rejection as the results in the WAVE software equals 45% based on the product and feed TDS.

6.1.3.2 Tank and Piping Sizing

The chosen tank has a capacity of 5 gallon, This RO Tank has been tested and certified by NSF international under NSF/ANSI standard 58 for material and structural integrity requirements, Table 6-5 shows the features and specifications of the tank.

Table 65 Features and Specifications of RO Tank

Features & Specification:
Model # RO-152 From PA-E Machinery Co. Ltd
Tank are Pre-Charged at 6 PSI
1/4" stainless Steel Connection built for Reverse Osmosis water storage tank, pump tank & thermal tank applications
Brass Cap with internal O-Ring guarantees No Air from air vent
Smooth internal air vent cap prevents diaphragm damaged
Package includes tank and tank holding bracket only

The pipe that will be used is PVC pipe which is durable, hard to damage, and long lasting. PVC Pipes do not rust, rot, or wear over time. For that reason, PVC piping is most commonly used in water systems, underground wiring, and sewer lines.

And by using Friction Loss Chart[17], assuming there is one gallon per minute –the smallest GPM in the table- of flow rate which is the most suitable for this system and the schedule 40 PVC pipe with ¾ inch of flex pipe, the friction loss equals 0.83ft [0.252984m].

The Discharge height equals 0.2794m which is the distance of the water inside the tank and the Demand pressure equals to 0.55m.

Total head and flow are the main criteria that are used to compare one pump with another or to select the type of the pump for an application. Total head is related to the discharge pressure of the pump.

$$H_{Total} = \text{Discharge height} + \text{Demand Pressure} + \text{Friction Loss} \quad (5)$$

Total head pressure required = 0.25+0.28+0.83 = 1.36 m.

6.1.3.3 Pump Selection

The system includes one pump, that is the high-pressure pump. High Pressure pump is used to increase the pressure of feed water, the pressure needs to be sufficiently high to overcome the naturally occurring osmotic pressure and force water from the feed water side through the Reverse Osmosis Membrane to the permeate water side.

`WAVE software bring out the pressure of the pump that needed is 1.5 bar. The chosen Pump is Huining High Flow Pressure Booster Pump for Reverse Osmosis, the specifications of the Pump are listed in table 6-6.

Table 66 Specification of DC Pump

Pressure	25 Psi
Flow	378 LPM
Voltage	24 V_{DC}
Power	11 Watt
I rated	0.5 A
I start	2 A

6.1.3.4 PV Module

The selected pump can be driven easily by small PV panel, a single photovoltaic module was used because it is enough to operate the 11 watt DC Pump.

$$\text{Required PV Power} = I\ \text{start} * V\ \text{pump} = 48W \qquad (6)$$

The pump used powered with 24 volt and 11 watt, accordingly, the PV panel used should be suitable to power the pump, so it should produce more than 11 watt and with a voltage of 24 volt. However, the selected Panel is High Efficiency Multicrystalline PV Module with 50 watt and 24 volt. The specification of the photovoltaic is illustrated in Table 6-7

Table 67 The Specifications of The PV Panel

Maximum Power (Pmax)	50W
Voltage at Pmax (Vmp)	36.46V
Current at Pmax (Imp)	1.37A
Open-Circuit Voltage (Voc)	44.62V
Short-Circuit Current (Isc)	1.46A
Operating Temperature	-40˚C to 85˚C
Maximum System Voltage	1000V DC

On a sunny day, the photovoltaic Panel SLP050-24U (50W), which converts solar radiation energy to electricity, was connected parallel into Booster DC Pump to operate it, without the need of using any inverter or converter; it is used to increase the feed water pressure.

The pressurized feed water enters the reverse osmosis membrane at a certain pressure to allow water molecules to pass through the membrane but prevent passage of salts and other contaminants. Figure 6-5 shows the PVRO design

7. Chapter Seven

7.1 Result and Discussion

7.1.1 Effect of Solar Radiation

The system was simulated throughout the year, in order to study the effect of solar radiation on the system performance. As can be seen in figure 7-1 there is almost a direct proportional relationship between the power input to the pump and the solar radiation.

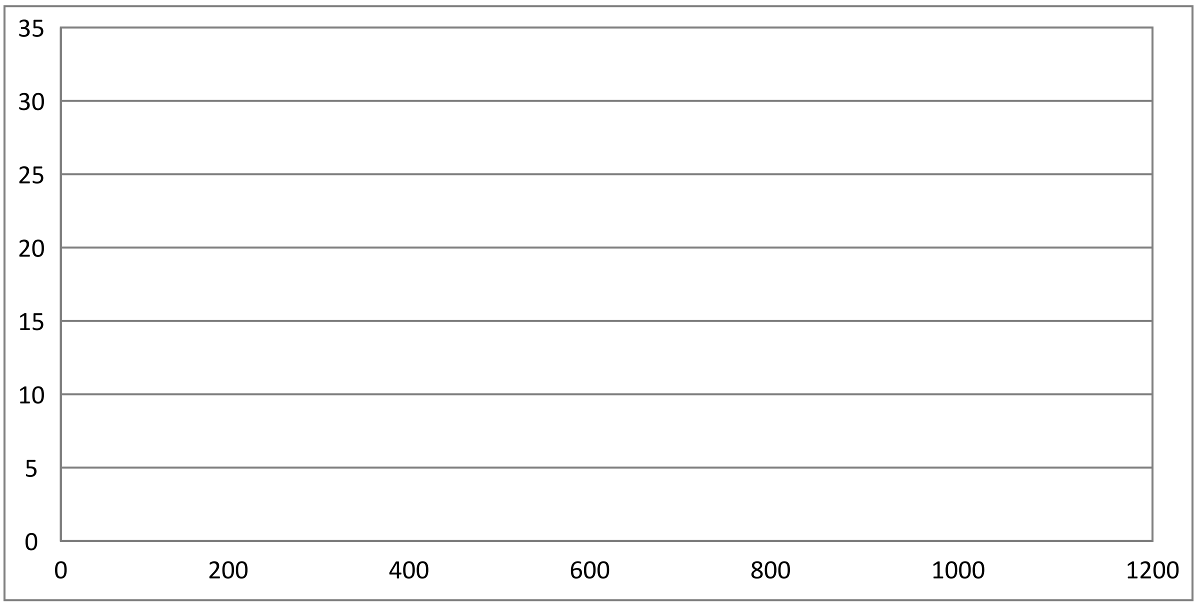


Figure 7-1 Effect of solar radiation on power input to the pump

The two figures below show the best and worst months through the year and the relationship for each one of the flow rate and the DC power through thirteen days, Figure 7-2 is for June where is the best case and Figure 7-3 is for December where is the worst case.

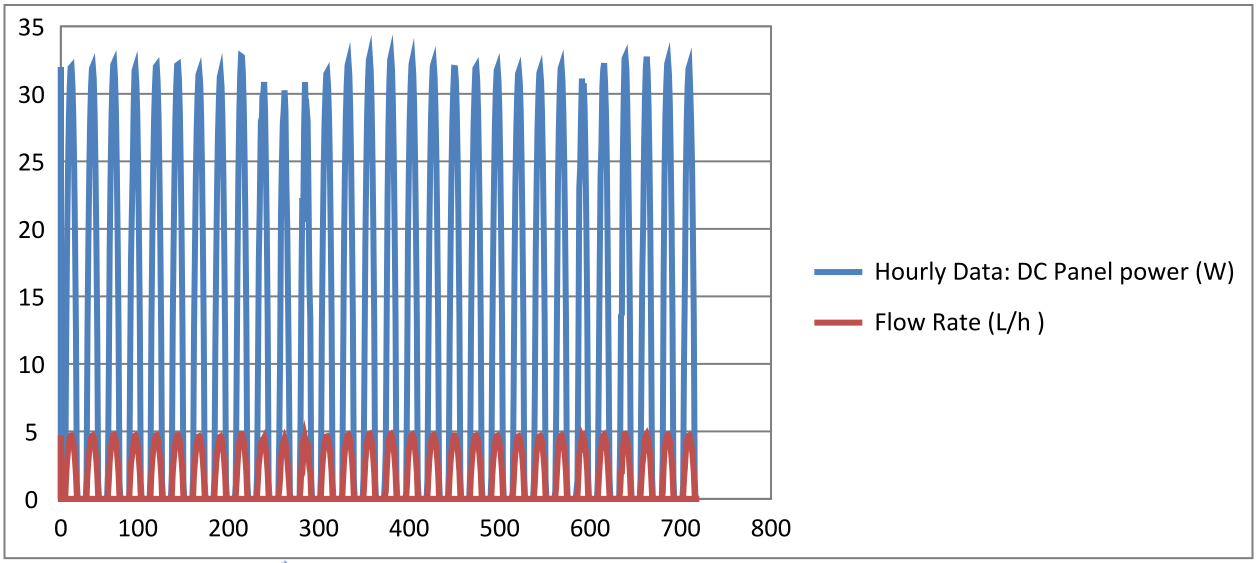


Figure 72 Relationship between the power input to the pump and flow rate of June

As known, the maximum solar radiation can be obtained in June, and minimum solar radiation in December as shown in figures 7-2 and 7-3 respectively. In June, the average solar radiation was (8.25)kW.hr/m².day .At this value the PV panel provides electrical current directly to the high pressure pump, whose speed increases as the power from the PV panel increases. The average permeate water produced was 43.8 L/d with 9 h of operation. In December, the average solar radiation was (2.84) kW.hr/m².day and the average permeate water produced was 5.83 L/d.

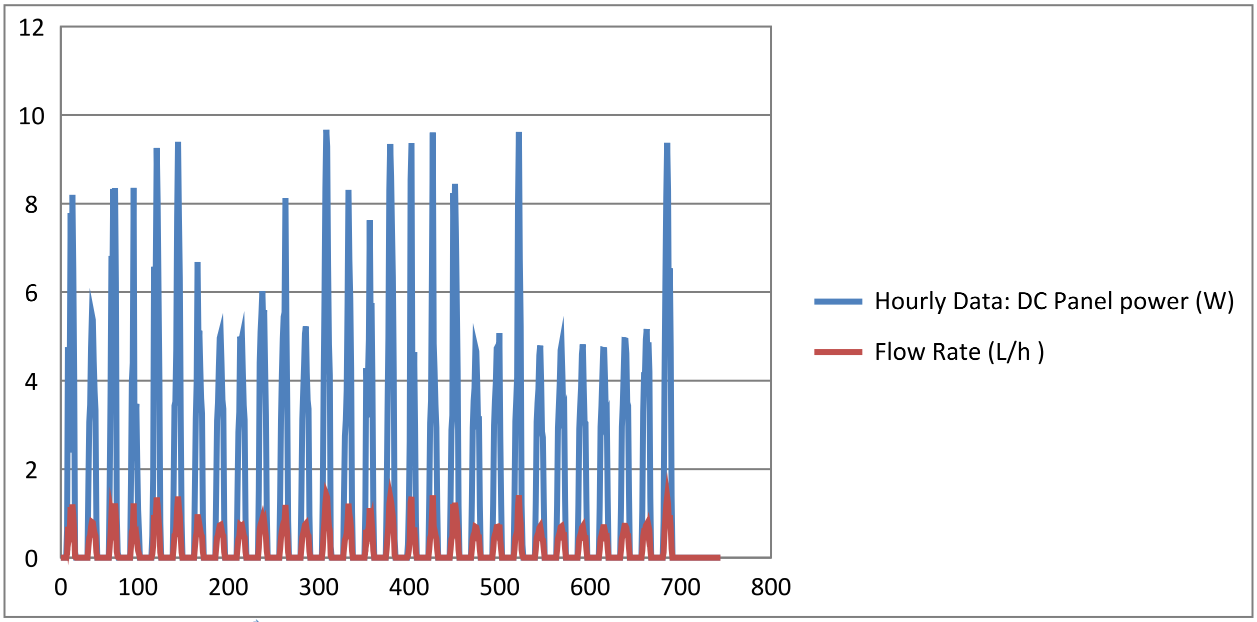


Figure 73 Relationship between the power input to the pump and flow rate of December

As a result, can conclude that the PV panel provides electrical current directly to the high pressure pump whose speed increases as the power from the PV panel increases. And therefore the permeate water flow increases with increasing the photovoltaic panel power.

7.1.2 Effect of water flow rate

Also as can be seen in figure 7-4 there is almost a direct proportional relationship between the power input to the pump and permeate flow rate.

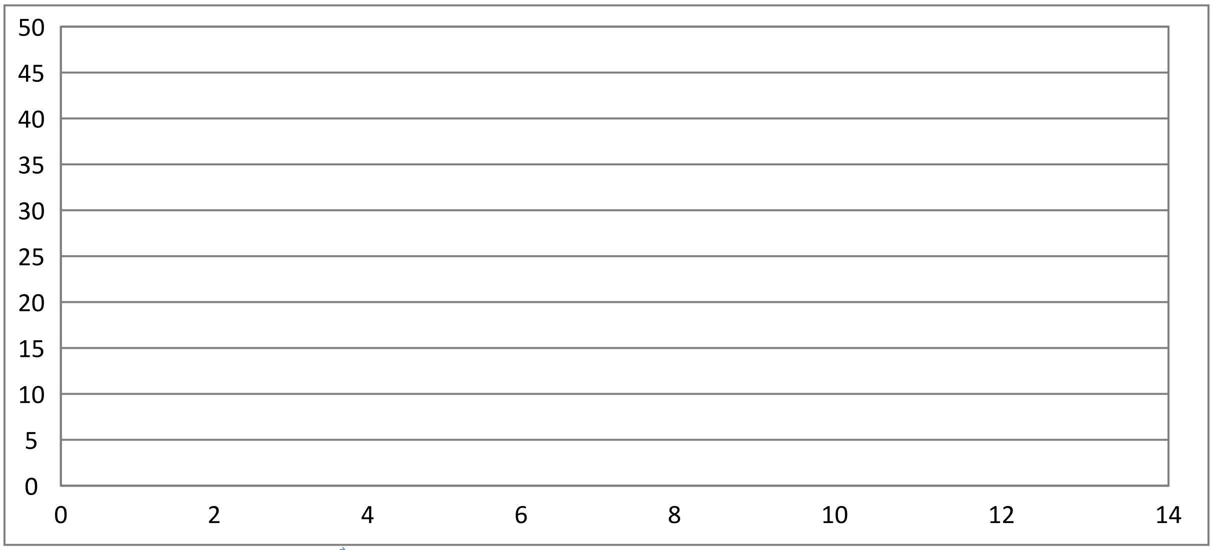


Figure 74 Effect of power input to the pump on permeate flow rate

Figure 7-5 shows a comparison between the required daily water and the average generated water during the year

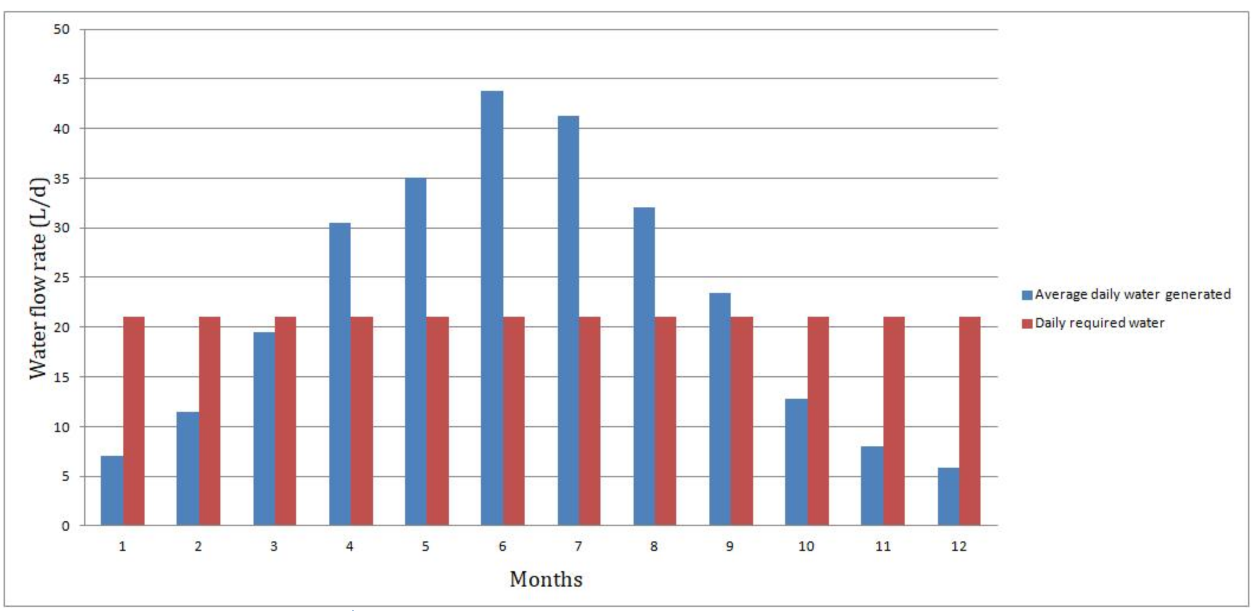


Figure 75 Comparison between the required and generated flow rate

as it shows in the last figure the amount of water required in those months (April, May, June, July, August and September) is completely covered which is due to the high solar radiation while in January, February, October, November and December it is less than the required which make the design not visible in this time of the year.

Figure 7-6 show the results of the power in June month by using SAM software

C	D	E	F	G
Hours since 00:00 June	Hourly Data: DC Panel power (W)	DC Panel power (KW)	Flow Rate (L/h)	
0	0	0	0	June
1	0	0	0	
2	0	0	0	
3	0	0	0	
4	0	0	0	
5	0	0	0	
6	0	0	0	
7	1.40296	0.00140296	0.205954528	
8	3.60976	0.00360976	0.529912768	
9	13.0064	0.0130064	1.90933952	
10	22.0887	0.0220887	3.24262116	
11	27.5904	0.0275904	4.05027072	
12	30.6901	0.0306901	4.50530668	
13	32.531	0.032531	4.7755508	
14	32.8318	0.0328318	4.81970824	
15	31.8066	0.0318066	4.66920888	
16	29.3587	0.0293587	4.30985716	
17	25.4226	0.0254226	3.73203768	
18	20.1004	0.0201004	2.95073872	
19	13.4945	0.0134945	1.9809926	
20	1.5421	0.0015421	0.22638028	
21	0	0	0	
22	0	0	0	
23	0	0	0	

76 SAM software power result for June

8. Chapter Eight

8.1 Economic Evaluation of Small RO Unit Powered By PV System

8.1.1 Cost analysis

It is one of the most important steps in solar-powered water desalination system. The photovoltaic energy system differ from conventional energy systems in that they have high initial cost and low operating costs.

The average daily water flow rate can be calculated as the following:

During June, the average flow rate 43.8 L/day, (day=10 hours) and the monthly average solar radiation was 8.25 kWh/m².day. According to other months, the average water flow rates were calculated corresponding to the monthly average solar radiation as shown in table 8-1.

Table 81 Average water flow rates.

Month	Power (W)	Monthly average solar radiation kW.h/m².day	Water Flow rate (L/day)
1	2	2.89	7
2	3.25	3.25	11.45
3	5.5	5.23	19.5
4	8.65	6.25	30.5
5	9.94	7.56	35
6	12	8.25	43.8
7	11.35	8.17	41.3
8	9	8.10	32
9	6.63	6.30	23.4
10	3.64	4.70	12.85
11	2.27	3.56	8
12	1.7	2.84	5.83

The major cost elements for water treatment plants are capital cost and annual operating costs. To determine the average annual cost of the water treatment system, it depends on common economic parameter such that interest rate, expected lifetime and total initial investment. These parameters are listed below:

- System life time is 25 years.
- Membrane life time is 5 years.
- Operating days per year are 365 days.
- Operating and maintenance (O&M) costs are 6% of the system annual payment.
- Interest rate is 10%.
- Availability factor (f) is 74%.
- Capacity (M) = 21 L/day.
- Salvage value of the units will be zero.

Capital Cost

the cost analysis of the system has summarized below in table 8-2.

Table 82 Capital Cost Summary

Component	Price
Case	$ 30
Tank	$ 55
HP Pump	$ 50
RO Unit	$ 50
Pipes	$ 2
Valve	$13
PV Panel	$ 100
Total	$301

Capital Cost = Device Price = $300

Annual Operating Cost

Annual operating cost covers all expenses after commissioning and during the actual operation.

Fixed Charge

The fixed charges factor is a function of the interest rate (i) which is value 10% of the capital and the numbers of years over which the investment is recovered which is value 25 years. To determine the fixed charge value of the capital costs, these costs are multiplied by an amortization factor (a).

The fixed charges factor can be calculated using the following relationship [17]:

(9)

(10)

$a = 0.11\ y_{-1}$

Annual fixed charges (

(11)

$A\ fixed = (\ 0.11\ y-1)\ \ (\ \$300) = 33.11\ \$/year$ (12)

Operating and Maintenance (O&M) Costs

This includes the operation and maintenance staff cost, cost of spares, etc. This cost shall be expressed on a yearly basis for each item for all the commercial operation period. The annual O&M costs are estimated at 20% of the plant annual payment [17].

$AO\&M = (6\%)\ \ (Afixed)$ (13)

$AO\&M = (6\%)\ X\ (33.11\ )\ \$/Year = 1.9\ \ \$/Year.$

8.1.2 Membrane Replacement

Replacement rate may vary between 5% - 20% per year [18].

Membrane life time is 5 years, It needs a replacement throughout 25 years, so every five year 57$ should be paid which is 285 $ for 25 years

Total annual cost (

(15)

$A_{total} = A_{fixed} + A_{replacement} + A_{M\&O}$

Unit production cost (

(16)

Where The average water flow rate =21 L/day, Capacity(M) =21 L/day and Plant availability (f) is 74%.

= 8 $/m³

8.1.3 Life Cycle Cost

For the present system, the life cycle cost will be estimated as follows:

- The life cycle of the system components will be considered as 25 years.
- The interest rate is about 10%.

The initial cost of the system =case cost + PV Panel cost + reverse osmosis membrane cost +HP Pump cost

+ Tank cost +Pipes and valve cost .

The initial cost of the system = $300 .

The annual maintenance and operation cost is about 6% of initial cost which is equal

18 $/year, salvage value of the system will be zero.

The life cycle cost of unit is obtained by drawing cash flow as in figure 8-1.

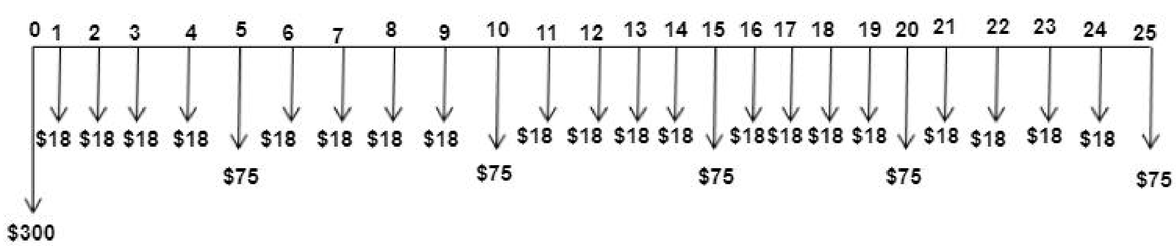


Figure 81 Cash Flow for Unit

The life cycle cost of the system = initial cost of the system + present worth of maintenance and operation present worth of salvage value.

The life cycle cost of the system = $300 + 18 (P/A,i,n) – 0 .

$$P = A[\quad],\ i \neq 0 \tag{17}$$

P = A (9.077)

(P/A,i,n) = 9.077
PW = $300 + (18 9.077) =$463.38

Then the equivalent annual worth AW is obtained with appropriate A/P, as follow:

AW = PW(A/P,i,n) =$463.38(A/P,10% ,25).

(18)

A=P (0.11017)

(A/P,10% ,25) = 0.11017

AW =$463.38 X 0.11017 = $51.05

8.2 Conclusion and Recommendation

In this work a simple study is done for as a sustainable solution for water and energy issues also for Springs excess water . Reverse Osmosis Powered by PV has been designed as a portable device Using WAVE and SAM software were the performance during the year and various environmental conditions have been studied in order to determine the optimal case of this device and the produced water flow rate with the power of the pump where the device covered only the required flow rate only in the summer months and also DC pump could be directly coupled with PV panel but with attention to the DC voltage otherwise controller preferred to be used and if there is some excess power UV Purification can be used to benefit from it. This device has several characteristic whereas it is environmentally friendly, economical and easy to use.

This system has been designed as a special case for a spring that has a certain TDS that is considered under the standard conditions with high potassium percentage that means the system can be changed in other cases, also the system can be developed to large scales systems to be suitable for the water quality of the case also filters can be added due to the pollution of the water. The device can be power by AC current at homes by adding other components such as inverter and controller because it doesn’t consume large amount of energy but in this study the system has been designed for remote areas and emergency situations.

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