AN-NAJAH NATIONAL UNIVERSITY
FACULTY OF ENGINEERING

GRADUATION PROJECT

WATER DESALINATION SYSTEM
BY
SOLAR ELECTRIC POWERED
REVERSE OSMOSIS

BY

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Abbreviations

AM	Air Mass
AC	Alternating Current
A.D	Anno Domini
A_{fixed}	Annual Fixed Charges
ACF	Average Concentration Factor
CC	Capital Cost
cfu	Colony Forming Unit
I_{mpp}	Current Maximum Power Point
DC	Direct Current
ED	Electro Dialysis
FC	Fecal Coliform
kWh	Kilowatt Hour
KCL	Kirchhoff's Current Law
MF	Microfiltration
MENA	Middle East and North Africa Countries
MCM	Million Cubic Meter
MEB	Multi effect Boiling
MSF	Multistage Flash
NF	Nan filtration
NTU	Nephelometric Turbidity Units
V_{oc}	Open Circuit Voltage
O&M	Operating and Maintenance
PPM	Parts Per Million
PSH	Peak Sun Hours
PV	Photovoltaic
RO	Reverse Osmosis
I_{sc}	Short Circuit Current
Si	Silicon
STC	Standard Test Conditions
TFC	Thin film Composite
TDS	Total Dissolved Solids
UF	Ultra filtration
UN	United Nation
VC	Vapor Compression
Vmpp	Voltage Maximum Power Point
W_P	Watt Peak
WHO	World Health Organization

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INTRODUCTION

Chapter One
Introduction

1.1 Scope

Water resources are essential for satisfying human needs, protecting health, and ensuring food production, energy and the restoration of ecosystems, as well as for social and economic development and for sustainable development [1]. However, according to UN World Water Development Report in 2003, it has been estimated that two billion people are affected by water shortages in over forty countries, and 1.1 billion do not have sufficient drinking water [2]. There is a great and urgent need to supply environmentally sound technology for the provision of drinking water.

1.2 water and energy

Water and energy are the major factors necessary for the development Of social and economic sectors in rural areas .Palestine has a large number Of rural villages lacking water and electricity networks connecting these Villages with electric grids of the nearest cities is nearly impossible, at least For another decade, due to their remoteness, low population count and low Electric energy demands. On the other hand Palestine has one of the highest Solar energy potential of all the countries in the world. It enjoys over 2800 Hours of sunshine every year; with an annual average daily solar radiation Intensity amounting to 5.4kwh\m2-day brackish water is available in very

Large amount in some areas of Palestine, particularly in Jordan valley.

1.3 Water Treatment Systems and Photovoltaic Power

A water treatment system needs a source of power to operate. In general, AC powered system is economic and takes minimum maintenance when AC power is available from the nearby power grid. However, in many rural areas, water sources are spread over many miles of land and power lines are scarce. Installation of a new transmission line and a transformer to the location is often prohibitively expensive.

Today, many stand-alone type water treatment systems use diesel engines. However, they have some major disadvantages, such as: they require frequent site visits for refueling and maintenance, and furthermore diesel fuel is often expensive and not readily available in rural areas of many developing countries.

The consumption of fossil fuels also has an environmental impact, in particular the release of carbon dioxide (CO_2) into the atmosphere. CO_2 emissions can be greatly reduced through the application of renewable energy technologies, which are already cost competitive with fossil fuels in many situations. Good examples include large-scale grid-connected wind turbines, solar water heating, and off-grid stand-alone PV systems [3]. The use of renewable energy for water treatment systems is, therefore, a very attractive proposition.

1.4 Energy Storage Alternatives

Needless to say, photovoltaic are able to produce electricity only when the sunlight is available, therefore stand-alone systems obviously need some sort of backup energy storage which makes them available through the night or bad weather conditions.

Among many possible storage technologies, the lead-acid battery continues to be the workhorse of many PV systems because it is relatively inexpensive and widely available. In addition to energy storage, the battery also has ability to provide surges of current that are much higher than the instantaneous current available from the array, as well as the inherent and automatic property controlling the output voltage of the array so that loads receive voltages within their own range of acceptability [4].

The type of lead-acid battery suitable for PV systems is a deep-cycle battery [5], which is different from one used for automobiles, and it is more expensive and not widely available.

Battery lifetime in PV systems is typically three to eight years, but this reduces to typically two to six years in hot climate since high ambient temperature dramatically increases the rate of internal corrosion. Batteries also require regular maintenance and will degrade very rapidly if the electrolyte is not topped up and the charge is not maintained. They reduce the efficiency of the overall system due to power loss during charge and discharge. Typical battery efficiency is around

85% but could go below 75% in hot climate [3]. From all those reasons, experienced PV system designers avoid batteries whenever possible.

1.5 project site

Al-Maleh village is located directly on the main street connecting the Town toubas with the Jordan valley .it is elevated at 12 m below sea level in North part of Jordan valley .the village is known for hot summer months, The monthly average of maximum temperature for six months, April – September, amounts to 41° C, while the annual daily average is 22.4 ° C.

The chemical analyses of the **Zbaidat tank** are:

Name	Feed(mg\l)
NH4	**0.00**
K	**13.10**
Na	**483.00**
Mg	**146.00**
Ca	**200.00**
Sr	**0.00**
Ba	**0.00**
CO3	**1.81**
HCO3	**305.00**
Cl	**36.00**
F	**0.00**
SO4	**157.00**
SiO2	**21.60**
Boron	**0.46**
CO2	**7.85**
TDS	**2566.15**
pH	**7.60**

1.6 project Aims

This project investigates the following:

- Determine the performance of reverse osmosis water desalination systems powered by solar electric energy under Palestine weather and environmental conditions.
- study the system design and sizing
- Determine the techno-economic feasibility of using solar electric systems.
- Identify the effects of desalination of brackish water on the environment, health and social conditions, in rural areas.
  Water desalination technology
- Water treatment methods and the energy consumption.
- Application of solar energy in springs and underground water treatment.
- Building an integrated system consisting of suitable membrane that can be powered by solar energy.
- Determination of the quality of surface water treatment by autonomous solar-powered membrane cells under Palestinian weather and environmental conditions.

Chapter Two

Water Treatment Methods

Chapter Two

Water Treatment Methods

2. Water Treatment Processes

This chapter introduces treatment of surface water processes starting with the history of treatment and its needs and moving on to the classifications of treatment of surface water processes.

2.1 Needs for Water Treatment

Water is an important resource for use of mankind and it is a resource for Life. It is important for agricultural and industrial growth, as well as for supporting growing populations who require a safe drinking water supply.

Natural resources cannot satisfy the growing demand for water with industrial development, together with the increasing worldwide demand for supplies of safe drinking water.

This has forced mankind to search for another source of water. In addition, the rapid reduction of subterranean aquifers and the increasing salinity of these non-renewable sources will continue to exacerbate the international water shortage problems in many areas of the world.

2.2 History of Water Treatment

Processes of water treatment has been practiced in the form of distillation process for over 2000 years, it is not until the eighteen century

A.D, for people to recognize that the distillation process could be enhanced by cooling the condensing surface.

In the eighteenth century A.D, Jaber Bin Hayyan an Arabic scientist wrote about the foundations of the treatment process using distillation.

The thermal desalination process for water distillation was the technology employed in the first major treatment plants in the 1950s which were predominantly in the Middle East region.

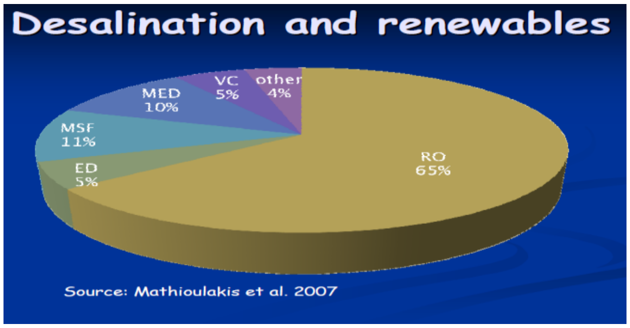
Membrane technologies were developed in the 1960s and 1970s and by the late 1980s, reverse Osmosis desalination technology made up 40% of desalination plants worldwide. This has now increased to levels approaching 60% [13].

Large improvements in membranes have caused the increased use of reverse osmosis, which have led to greater efficiencies and reduced energy consumption. Such advances have also resulted in electro dialysis now being significantly more expensive than reverse osmosis technology; By contrast, the distillation method uses high energy consumption to heat the water. This major drawback means thermal plants now have higher capital and operating costs than reverse osmosis technology.

2.3 water technology

The desalination plants presently producing fresh water from saline water are operating mainly on the processes: multistage flash (MSF), vapor compression (VC), electro dialysis(ED) and reverse osmosis (RO).

This picture show increasing of RO application for desalination due to lower energy consumption as show in table below:


Desalination and renewables

Source: Mathioulakis et al. 2007

Process Name	**Electrical energy requirements**	**Thermal energy requirements**
RO	**5 KWh\m^3** ⇨ (3500ppm) 15**KWh\m^3** ⇨ (35,000ppm)	-
MSF	**3-5 KWh\m^3**	**60-80 KWh\m^3**
MED	**2.3 KWh\m^3**	**60-80 KWh\m^3**

2.4 Classification of Water Treatment Processes

Many methods have been proposed for water treatment processes, as can be seen the major processes in figure 2.1,

1. Processes in which treatment taking place involves phase change.

- Multistage flash (MSF)**.**
- Multi effect boiling (MEB).
- Vapor compression (VC).

2**.** Processes in which treatment takes place without any phase change. These include the following two main methods:

- Reverse Osmosis (RO).
- Electro dialysis (ED).

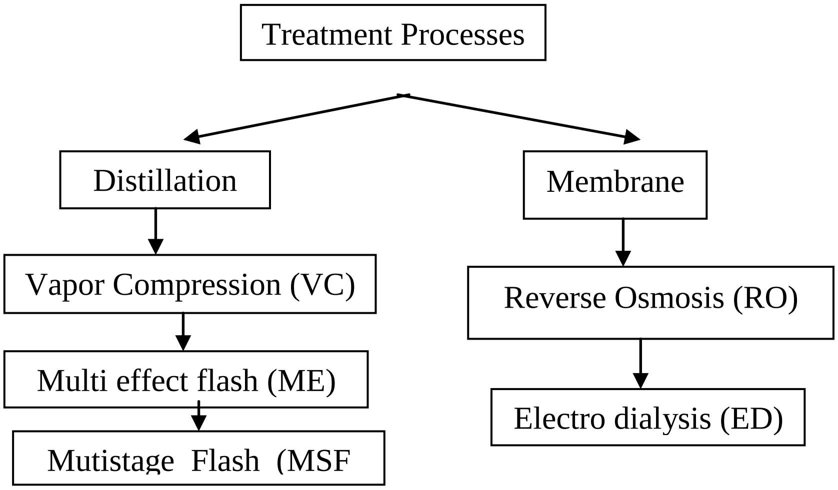


Figure (2.1): Classification of treatment of water processes

2.4.1 Distillation Professes

2.4.1.1Vapor Compression Distillation (VC)

It is a system that treats surface water. The System combines the benefits of distillation with those of vapor compression to greatly lower the cost of distillation for removal of water or concentration of other ingredients. It can be used for a broad range of applications and provides substantial economic and operational benefits to the user. Depending on local energy cost and the volume of liquids being processed. Vapor Compression is a prepackaged closed loop distillation system designed to treat a wide variety of water and process water streams through the use of advanced vapor compression technology.

The Vapor Compression Distillation process as follows:

1. The water entering the system is preheated, and gross solids removed.
2. The water is circulated through a specially designed plate and frame heat exchanger where the water is boiled into vapor. A mixture of water and vapor exit the heat exchanger and enter the separator.
3. The compressor draws the vapor from the separator and compresses it to about 0.35 bar, thereby increasing its temperature. The superheated vapor is then pumped into the condenser side of the heat exchanger where it is used to boil additional water in the evaporator side. As the hot vapor releases its latent heat, it condenses into distilled water, which is then discharged from the system.

4. As additional water is evaporated during the process, the remaining water becomes more concentrated. When the desired level of concentrate is reached, the concentrate is discharged, and more feed stock is added automatically to the system. The system treats industrial process and waste-water streams. It combines the benefits of distillation with those of vapor compression; the system has a wide range of applications and provides substantial economic and operational benefits to the user. Figure 2.2 illustrates the principle of vapor compression distillation.

The vapor-compression process consumes a small amount of energy and has a low operating cost. However, its capacity is limited, and the quality of water produced and maintenance costs do not match those by other distillation processes [11].

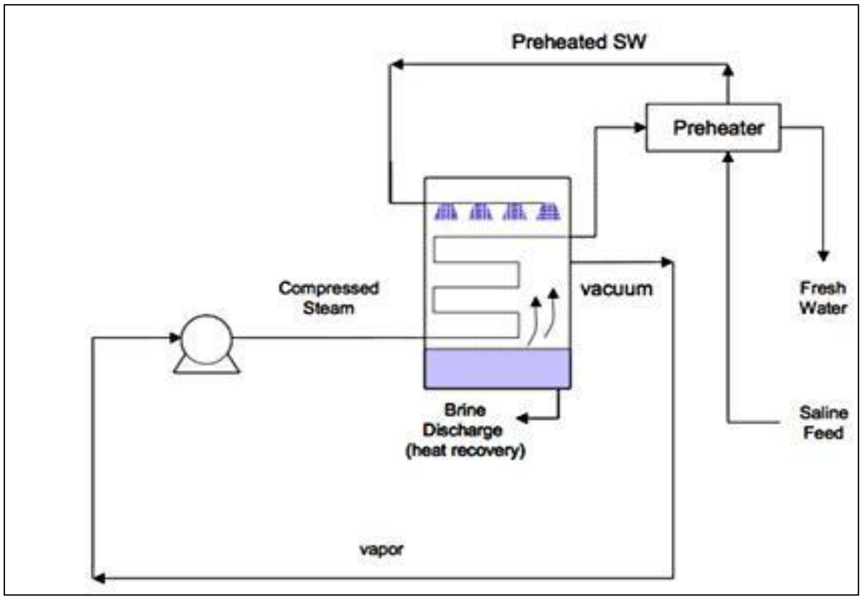


Figure (2.2): Principle of vapor compression distillation

2.4.1.2 Multistage Flash Distillation (MSF)

In Multi –Stage Flash evaporation, the water is heated and evaporated. The pure water is then obtained by condensing the vapor.

The water is heated in a vessel both the temperature and pressure increase, the heated water passes to another chamber at a lower pressure which cause vapour to be formed, the vapour is led off and condensed to pure water using the cold sea water which feeds the first heating stage.

The concentrated brine is then passed to a second chamber at a still lower pressure and more water evaporates and the vapour is condensed as before.

The process is repeated through a series of vessels or chambers until atmospheric pressure is reached. Multistage flash evaporation is considered to be the most reliable, and is probably the most widely used. The principle is illustrated in Fig 2.3 [12].

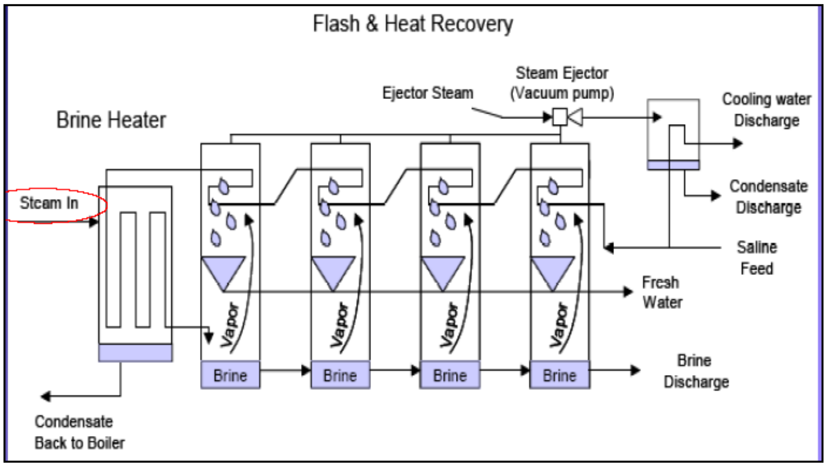


Figure (2.3): Multistage flash process (MSF)

2.4.1.3 Multi effect Boiling Distillation (MEB)

Multi effect distillation (MEB) is in principle similar to multi stage flash evaporation, except that steam is used to heat up the water in the first stage and the resulting vapour is used in subsequent stages to evaporate the water, and the water is used to cool and condense the vapour in each successive stage to that the temperature gradually falls across each stage of the process. The principle is illustrated in figure 2.4[12].

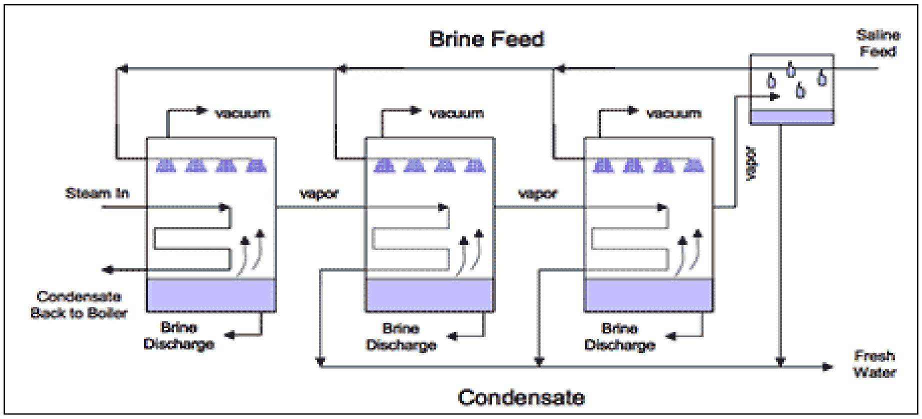


Figure (2.4): Multi effect boiling process (MEB)

2.4.2 Membrane Processes

The membrane performance in terms of the fluxes and selectivity are mainly dependent on the nature of the elements contained in the two phases and the driving forces applied.

This processes use relatively permeable membrane to move either water or salt to induce two zones of differing concentrations to produce fresh water.

The separation takes place at ambient temperature, without phase change, which offers energetic advantages over distillation, and the separation takes place without the accumulation of products inside the membranes. This separation does not require the addition of chemical additives.

Membrane process types

The main membrane processes used in water treatment are:

1. Microfiltration (MF).
2. Ultrafiltration (UF).
3. Nano filtration (NF).
4. Reverse Osmosis (RO).
5. Electro dialysis (ED).

2.4.2.1 Microfiltration Membrane

Membranes with a pore size of 0.1 – 10 µm perform microfiltration. Microfiltration membranes remove all bacteria. Only part of the viral contamination is caught up in the process, even though viruses are smaller than the pores of a micro filtration membrane. This is because viruses can attach themselves to bacterial biofilm. 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 liquid [13].

2.4.2.2 Ultra filtration Membrane

The pores of ultra filtration membranes can remove particles of 0.001 – 0.1 µm from fluids. Ultra filtration is a selective fractionation process utilizing pressures up to 145 psi (10 bars). It concentrates suspended solids and solutes of molecular weight greater than 1,000. The permeate contains low-molecular-weight organic solutes and salts. UF is widely used in the fractionation of milk and whey, and also finds application in protein fractionation [13].

2.4.2.3 Nan filtration Membrane

Nan filtration is a special process selected when RO and UF are not the ideal choice for separation. It is use partially permeable membranes to preferentially separate different fluids or ions, and will remove particles from approximately 0.0005 to 0.005 microns in size. Nan filtration membrane can perform separation applications that are not otherwise economically feasible, such as demineralization, color removal, and desalination. In concentration of organic solutes, suspended solids, and polyvalent ions, the permeate contains monovalent ions and low-molecular-weight organic solutions like alcohol [14].

2.4.2.4 Reverse Osmosis (RO) Membrane

Osmosis is a physical force. It is the natural tendency of water with a low concentration of dissolved particles to move across a semi-permeable membrane to an area of water with a high concentration of dissolved particles. The water will try to reach equilibrium on both sides, as shown in figure 2.5.

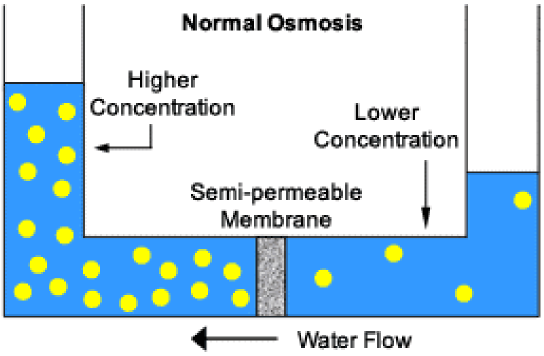


Figure (2.5): Principle of normal osmosis process

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 as in figure 2.6[15].

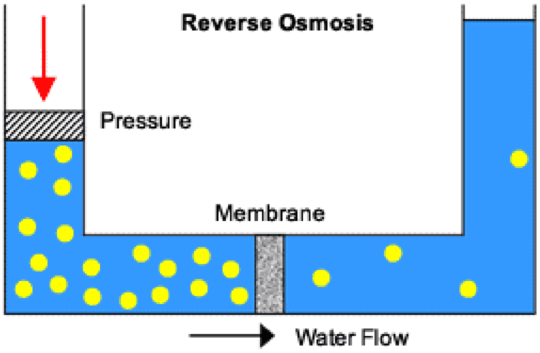


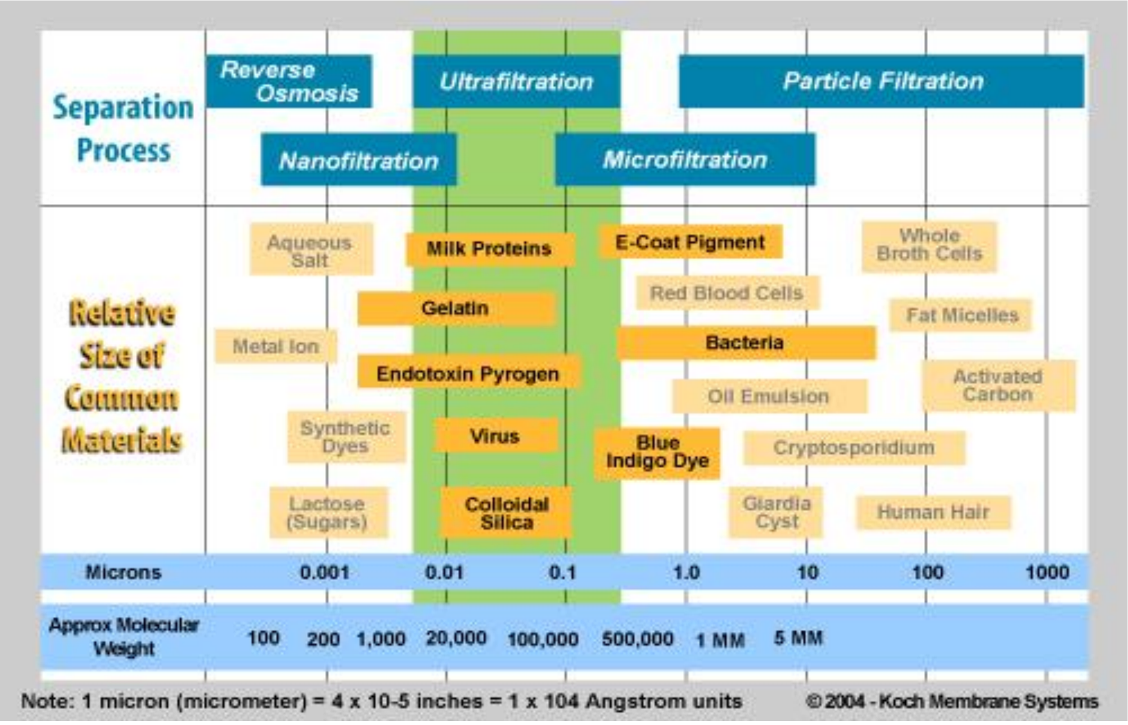
Figure (2.6): Principle of reverse osmosis process

The classification and comparison between these processes is based on many characteristics of each such as, as shown in figure 2.6

1. The driving force [hydrostatic or electrical].

2. The separation mechanism.

3. The nominal size of the separation achieved.



Note: 1 micron (micrometer) = 4 x 10-5 inches = 1 x 104 Angstrom units

©2004 - Koch Membrane Systems

Figure (2.7): Ranges of filtration system

2.4.2.5 Electro dialysis (ED)

It is a voltage driven process and uses an electric potential to move salts selectively through a membrane, leaving fresh water behind.

The salts in seawater are composed of positive ions (called cations) and negative ions (called anions). Electro dialysis uses a stack of ion-exchange membranes which are selective to positive and negative ions. Under the influence of a direct electrical current (DC), the positive sodium ions pass through a cation membrane and the negative chloride ions pass through an anion membrane.

The incoming saline water is thus converted into two streams, one of concentrated brine and one of desalinated (fresh water) [16].

This illustrated in Figure 2.7 Industrial electro dialysis plants consist of stacks of hundreds of membranes.

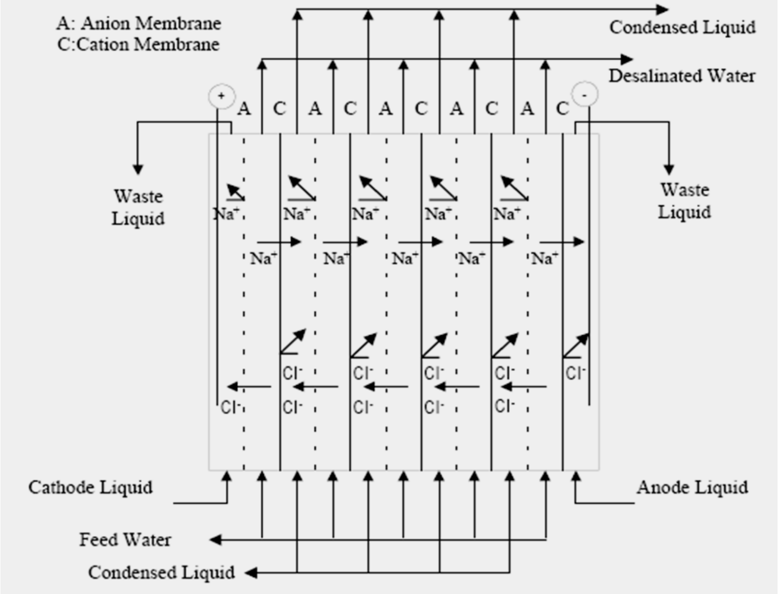


Figure (2.8): Principle of electro dialysis

CHAPTER THREE

REVERSE OSMOSIS PROCESS

Chapter Three
Reverse Osmosis Process

3.1 Introduction

To understand how reverse osmosis purifies water; you must first understand the process of osmosis.

a) **Principles of Osmosis**

Osmosis is the process in which water moves from a higher concentration to a lower concentration. A semi permeable membrane has nothing to do with the definition of osmosis. A membrane is not needed to actually do osmosis but osmosis can occur in the presence of a membrane as shown in figure 3.1.

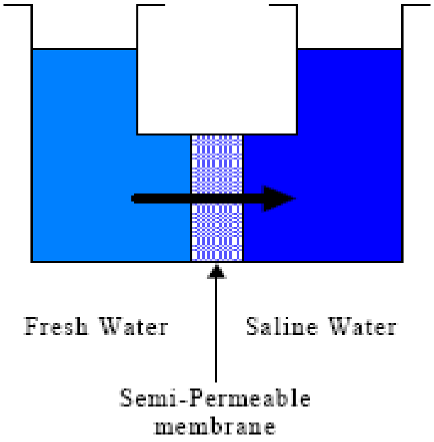


Figure (3.1): Osmosis process

B) Principle of Reverse Osmosis: 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 as shown in figure 3.2.

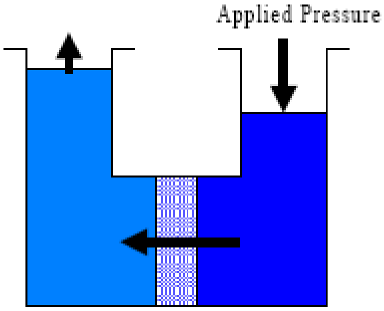


Figure (3.2): Reverse osmosis process

3.2 Process Description and Terminology

In practice, reverse osmosis is applied as a cross flow filtration process. The simplified process is shown in Figure 3.3.

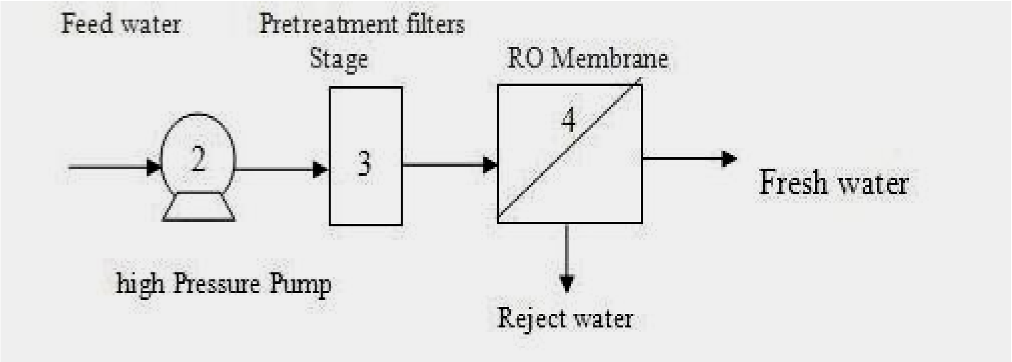


Figure (3.3): Reverse osmosis terminology

3.2.1 Booster (Diaphragm) Pump

The pump supplies the pressure needed to push water through the membrane, even as the membrane rejects the passage of salt through it. The pressure required depends on the concentration and temperature of the feed water.

Osmotic pressure increases with increasing concentration, so that the operating pressure must exceed the osmotic pressure corresponding to the concentration of the rejected brine at the membrane outlet.

3.2.2 Pretreatment Filters

The Feed water was treated from replaceable pre filter sediment- carbon cartridges.

- 5 Micron filter, removes sediment, clay, silt and particulate matter to 5 micron range.
- Carbon filter removes chlorine, harmful chemicals, synthetic detergents, as well as other organic contaminants.
- Compacted carbon block, where a combination of mechanical filtration and physical/chemical adsorption takes place to reduce or eliminate a wide range of contaminants.

3.2.3 Membrane Processes Technology

Reverse Osmosis Membrane Modules are commercially available in four configurations:

1. Spiral-Wound Module.
2. Hollow Fine Fiber Module.

3. Tubular Module.
4. Plate-and-Frame Module.

3.2.3.1 Spiral-Wound Module

It consists of two or more leaves (envelopes). Each leaf has two flat sheets of semi permeable membrane separated and supported by a porous backing material as shown in figure 3.4.

It is sealed on three sides and the fourth open side is attached to a perforated pipe.

A flexible feed spacer is added and the flat sheets are rolled into tight circular configuration.

The term spiral is derived from the fact that the flow in the rolled up arrangement of membranes and support sheets follows a spiral flow pattern.

The feed water can be applied to the inside of the fiber (inside out flow), or the outside of the fiber (outside-in flow) [17].

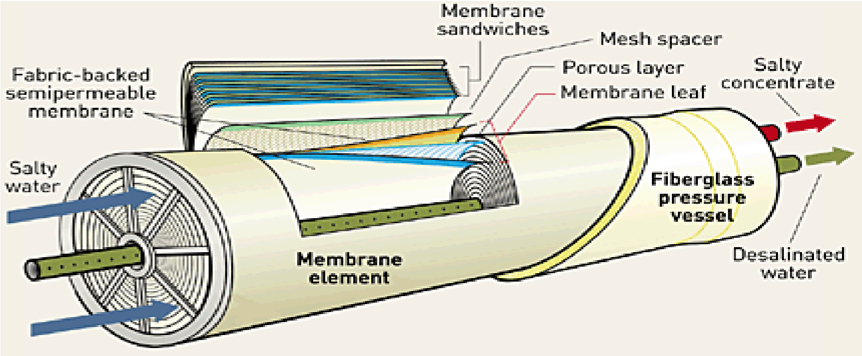


Figure (3.4): Spiral wound module

3.2.3.2 Hollow Fine Fiber Module

In hollow fiber modules hundreds to thousands of hollow fibers are bundled together to form a module. The entire assembly is inserted into a pressure vessel. The feed water can be applied to the inside of the fiber (inside out flow), or the outside of the fiber (outside-in flow) as shown in figure 3.5.

This configuration uses membrane in the form of hollow fibers which have been extruded from cellulosic or non-cellulosic material.

The hollow fiber membrane bundle, 10 cm to 20 cm in diameter, is contained in a cylindrical housing or shell approximately 137 cm long and 15 - 30 cm in diameter. The assembly is called a permeate. The pressurized feed water enters the permeate feed end through the center distributor tube, passes through the tube wall, and flows radially around the fiber bundle toward the outer permeate pressure shell. Water permeates through the outside wall of the fibers into the hollow core or fiber bore, through the bore to the tube sheet or product end of the fiber bundle, and exits through the product connection on the feed end of the permeate [17].

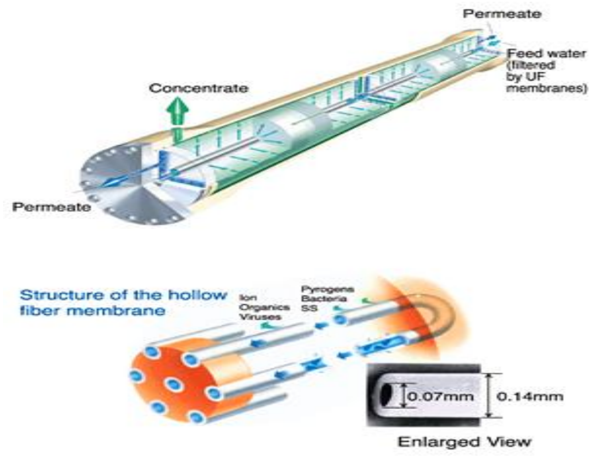


Figure (3.5): Hollow fine fiber module

3.2.3.3 Tubular Module

The description of tubular module with fourteen tubes each of 1.25 meter length and 18 mm internal diameters made up of fiber glass reinforced porous plastic tube and using Cellular Acetate as shown in figure 3.5.

Other membrane material can also be suitably casted in tubular form. The total area of the membrane packed in single module is about 1 m².

The typical membrane densities in tubular form are in the range of 60 – 160 m²/m³.

The standard velocity range of feed flow is 0.5 ft/sec to 1.5 ft/sec but even higher value up to 5 ft/sec are also acceptable at the cost of higher pressure drops in few specific applications with high turbidity solutions particularly in food and pharmaceutical industries This corresponds to a minimum volumetric feed flow of about 2.3 liter/minute and maximum feed flow of about 23 liter/minute with an optimum range of 5 –10 liter/minute feed flow rate [18].

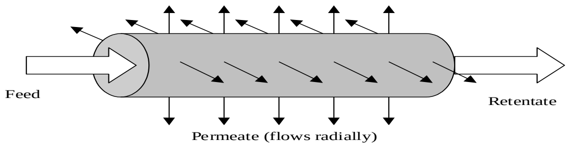


Figure (3.6): Tubular module membrane

3.2.3.4 Plate and Frame Module

As shown in Figure 3.7, Plate-and Frame modules use flat sheet membranes that are layered between spacers and supports. The supports also form a flow channel for the permeate water. The feed water flows across the flat sheets and from one layer to the next. Recent innovations have increased the packing densities for new design of plate-and-frame modules. Maintenance on plate-and frame modules is possible due to the nature of their assembly. They offer high recoveries with their long feed channels and are used to treat feed streams that often cause fouling problems [19].

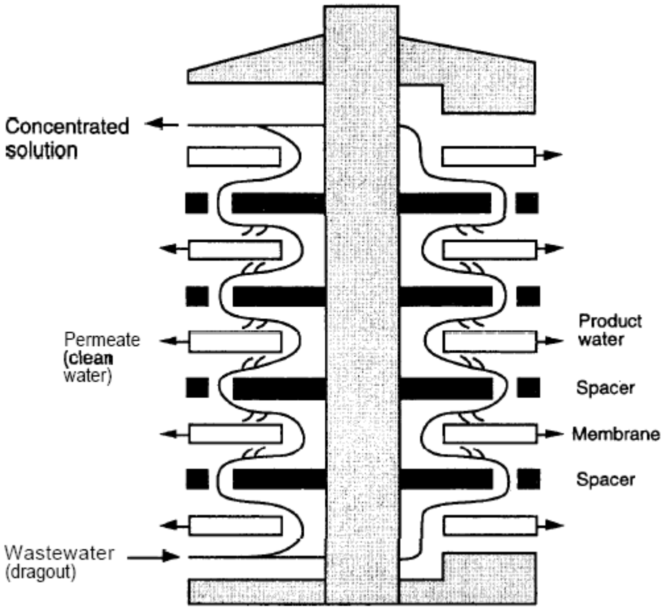


Figure (3.7): Plate-and-frame reverse osmosis module

An ideal Membrane has the following characteristics:-

1. High rate of fresh water

2. High salt rejection.

3. Resistant to high temperature.

4. Resist the presence of excess chlorine less part per million.

5. Resistant to all kind of fouling (inorganic, organic, colloidal, and microbiological Fouling).

6. It is not sensitive to attack bacteria.

7. It is not sensitive to the possibility of collapse with the high temperature and lack of discipline pH.

8. Chemically, physically, and thermally stable in saline water.

9. Long and reliable life.

10. Inexpensive.

There are the factors influencing the membrane performance as shown in figure3.8.

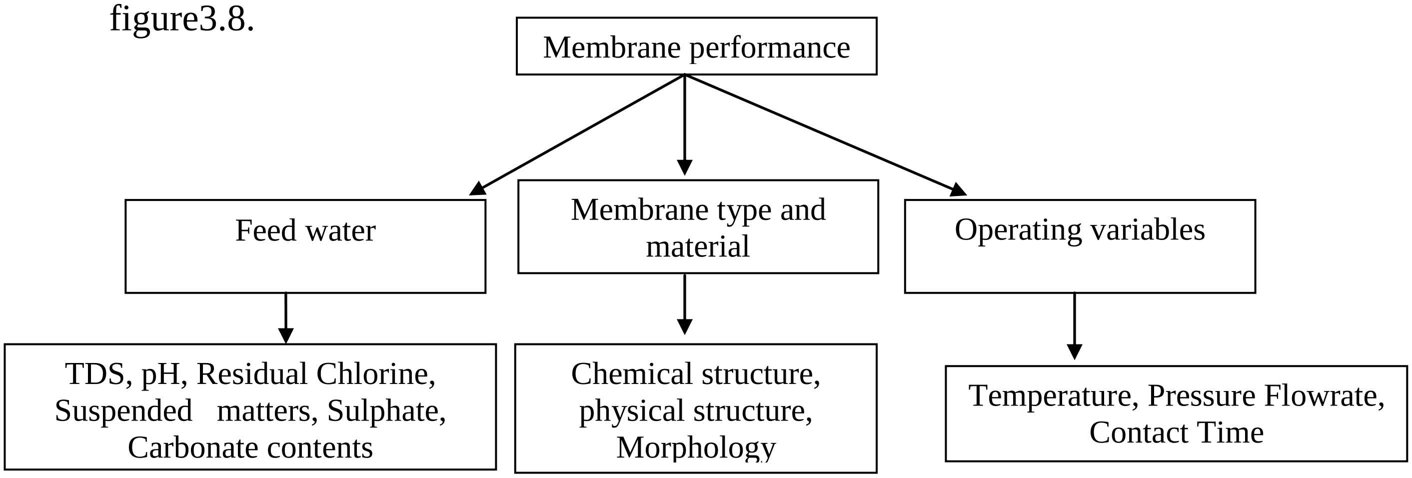


Figure (3.8): Factors influencing the membrane performance

3.3 Basic Transport Equations in Reverse Osmosis

The three streams (and associated variables) of the RO membrane process are shown in Figure 3.9: the feed, the product stream called the permeate, and the concentrated feed stream called the concentrate or retentate.

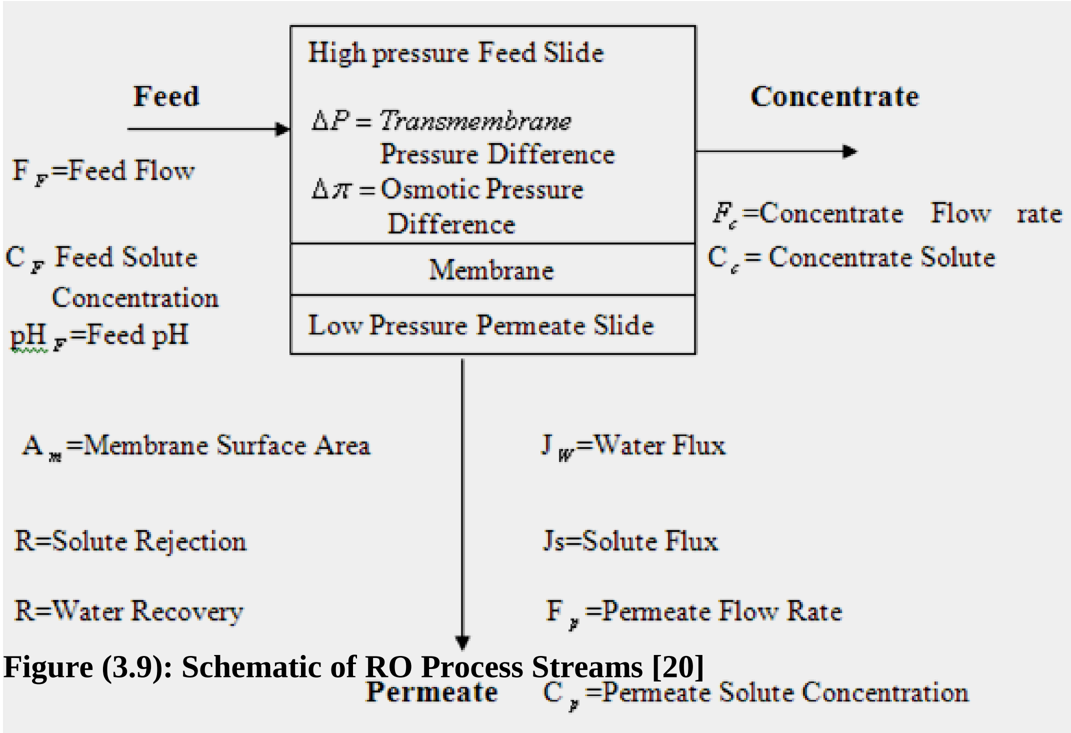


Figure (3.9): Schematic of RO Process Streams [20]

There are a set of terms and equations used to define the parameters governing transport across a membrane.

3.3.1 OSMOTIC PRESSURE

The osmotic pressure, P_{osm} of a solution can be determined experimentally by measuring the concentration of dissolved salts in solution [21]:

$$P_{osm} = 1.19(T+273) \times \sum (m_i) \qquad (3.1)$$

P_{osm} = osmotic pressure (in psi).

T = temperature (in °C).

$\sum(m_i)$ = sum of molal concentration of all constituents in a solution.

3.3.2 Water Flux

The following equation defines the water flux [22]:

$$J_w = K_1(\Delta P - \Delta\pi) \qquad (3.2)$$

$$K_1 = K_w\left(\frac{A}{\tau}\right) \qquad (3.3)$$

$$\pi = 1.21T\sum M_i \qquad (3.4)$$

Where

J_w = Water flux = [$m^3/m^2/sec$]

ΔP = Hydraulic pressure differential across the membrane = [atm]

π = Osmotic pressure differential across the membrane = [atm]

$K1$ =Pure water transport coefficient, i.e. the flux of water through

The membrane per unit driving force = [m3/m2/sec atm]

K_w = Membrane permeability coefficient for water.

A = Membrane area = [m]

τ = Membrane thickness = [m]

T = Feed water temperature = [K]

M_i = Molality of the ith ionic or nonionic materials.

It depends on the membrane properties, temperature of the system and the chemical composition of the salt solution.

3.3.3 Concentration Flux

The salt flux is an indicator for the membrane effectiveness in removing salts from water.

The salt flux is a function of the system temperature and the salt composition [22].

$$F_c = K_2 (C_F - C_c) \qquad (3.5)$$

Where

F_c = Concentrate Flow Rate = [Kg/m2/sec]

K_2 =Salt transport coefficient = [m/sec]

C_F = Feed Solute Concentration= [Kg/m3]

C_c = Product Solute Concentration = [Kg/m3]

As water flows through the membrane and salts are rejected by the membrane, a boundary layer is formed near the membrane surface in which the salt concentration exceeds the salt concentration in the bulk solution. This increase of salt concentration is called concentration polarization.

The effects of concentration polarization are as follows:

1. Greater osmotic pressure at the membrane surface than in the bulk feed solution, ΔP_{osm}, and reduced Net Driving Pressure differential across the membrane ($\Delta P - \Delta P_{osm}$).
2. Reduced water flow across membrane (Q_w).
3. Increased salt flow across membrane (Q_S).
4. Increased probability of exceeding solubility of sparingly soluble salts at the membrane surface, and the distinct possibility of precipitation causing membrane scaling.

3.3.4 Salt Rejection

Salt rejection expresses the effectiveness of a membrane to remove salts from the water.

It can be calculated from the following equation [22]:

$$\%\ \text{Salt rejection} = \left(1 - \frac{ProductConcentration}{FeedConcentration}\right) X100\% \qquad (3.6)$$

$$\%\ \text{Salt rejection} = \left(1 - \frac{CP}{CF}\right) X100\%.$$

The salt passage depends on the feed water temperature and composition, operating pressure, membrane type and material, and pretreatment.

Salt passage and bundle pressure drop are the two indicators of membrane fouling.

3.3.5 Recovery

The recovery rate for an RO system is [22]:

$$\text{Recovery} = \frac{F_P}{F_F} \qquad (3.7)$$

F_P = Permeate Flow Rate [m³/day]

F_F = Feed Flow Rate [m³/day]

The recovery rate affects salt passage and product flow.

As the recovery rate increases, the salt concentration on the feed-brine side of the membrane increases, which causes an increase in salt flow rate across the membrane.

A higher salt concentration in the feed-brine solution increases the osmotic pressure, reducing the net driving pressure and consequently reducing the product water flow rate.

3.4 Description of Variable Effects: Factors affecting RO membrane separations include: feed variables such as solute concentration, temperature, pH, and pretreatment requirements; membrane variables such as polymer type, module geometry, and module arrangement; and process variables such as feed flow rate, operating pressure, operating time, and water recovery.

Water flux is shown to increase linearly with applied pressure. This behavior is predicted by most of the RO transport models.

Water flux also increases with temperature, as would be expected, since the water diffusivity in the membrane increases and the water viscosity in the membrane decreases with temperature; the increase in water flux can usually be described by an Arrhenius temperature dependence of the water permeability constant or by water viscosity changes [23].

In addition, water flux is greater at higher feed flow rates (high feed velocities over the membrane surface) since this minimizes concentration polarization.

Water flux decreases with increasing feed solute concentration since the higher concentrations result in larger osmotic pressures (and so a smaller driving force across the membrane). This behavior is also predicted by most of the transport models. Water flux can also gradually decrease over operating time (measured in days or months of operation) because of compaction (mechanical compression) or other physical or chemical changes in membrane structure [23].

Solute rejection usually increases with pressure since water flux through the membrane increases while solute flux is essentially unchanged when pressure is increased; however, rejection of some organics with strong solute-membrane interactions decreases with pressure.

Rejection of solute remains constant or decreases with increasing temperature depending on the relative increases of water and solute diffusivities in the membrane.

For most simple inorganic systems (such as NaCl, Na2SO4) feed pH does not significantly affect water or solute fluxes. However, for ionizable organics, rejection is a strong function of feed pH: the organic is usually much more highly rejected when it is ionized.

Feed water quality is also important since particulates, colloids, or precipitates present in the feed can cause fouling of a membrane by depositing on its surface, resulting in a substantially reduced water flux. Bacteriological growth can also occur in RO membrane modules, forming bacterial layers that decrease water flux and, in some cases, degrade the membrane polymer.

Selected generalized curves illustrating the effects of some of these variables are shown in Figure 3.10 for non interacting solutes [23].

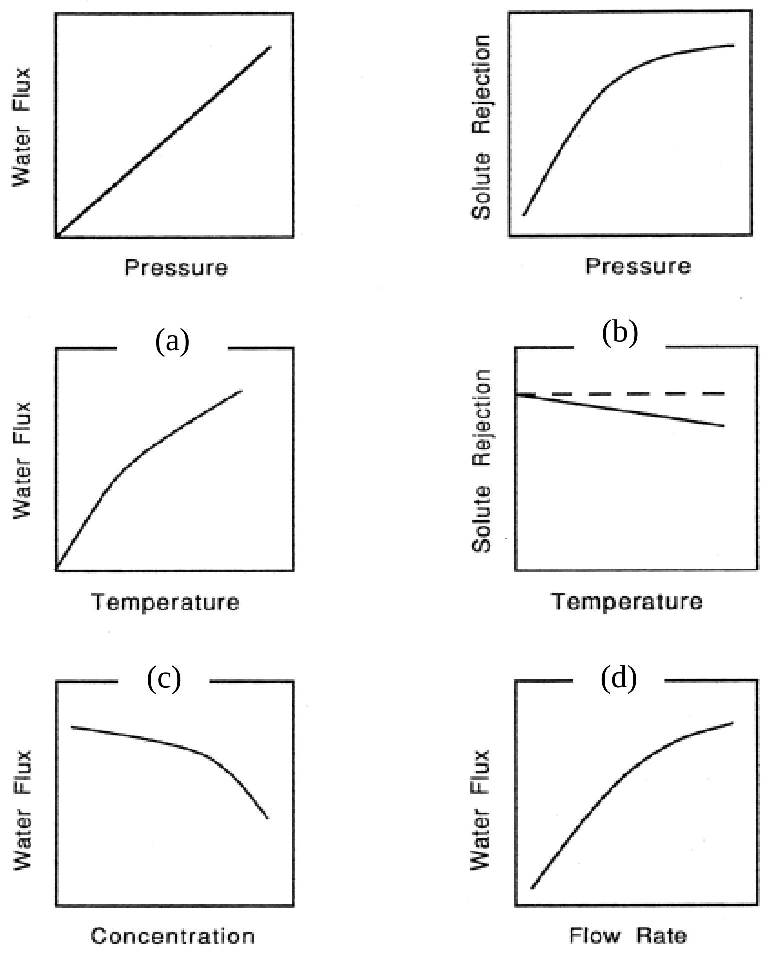


Figure (3 ffects of Variables on RO S tions [23]

- **a- Effect of pressure on water flux.**
- **b- Effect of pressure on solute rejection.**
- **c- Effect of temperature on water flux.**
- **d- Effect of temperature on solute rejection.**
- **e- Effect of concentration on water flux.**
- **f- Effect of flow rate on water flux.**

Chapter Four

Solar Energy and Photovoltaic Cell technology

Chapter Four

Solar Energy and Photovoltaic Cell technology

This chapter describes PV cell operation and the design and the operation of photovoltaic system.

4.1 Solar Radiation

For PV system, solar radiation is the most important data for preliminary design and sizing of a PV power system.

Palestine has one of the highest solar potentials of all the countries of the world.

Palestine enjoys over 2500 sunlight hours every year, with an annual average solar radiation intensity exceeding 5.3 kWh/m^2.day as shown in table 4.1.

Table (4.1): **Monthly average solar radiation in, Palestine [24].**

Month	kWh/m^2.day
1	2.89
2	3.25
3	5.23
4	6.25
5	7.56
6	8.25
7	8.17
8	8.10
9	6.30
10	4.70
11	3.56
12	2.84

In photovoltaic (solar) module light energy converts into DC electricity. Photovoltaic module is the basic element of each photovoltaic system. Physical phenomenon allowing light-electricity conversion - photovoltaic effect, was discovered in **1839** by the French physicist Alexander Edmond Becquerel. Experimenting with metal electrodes and electrolyte he discovered that conductance rises with illumination. Bell laboratories produced the first solar cell in 1954, the efficiency of this cell was about 5 %, and cost was not a major issue, because the first cells were designed for space applications [25].

In the following years solar cell efficiency increased while the cost has decreased significantly as shown in figure 4.1.

4.2 Photovoltaic Module

A single PV cell produces an output voltage less than 1V, about 0.6V for crystalline silicon (Si) cells, thus a number of PV cells are connected in series to achieve a desired output voltage. When series-connected cells are placed in a frame, it is called as a module.

Most of commercially available PV modules with crystalline-Si cells have either 36 or 72 series-connected cells. A 36-cell module provides a voltage suitable for charging a 12V battery, and similarly a 72-cell module is appropriate for a 24V battery. This is because most of PV systems used to have backup batteries, however today many PV systems do not use batteries; for example, grid-tied systems. Furthermore, the advent of high efficiency DC-DC converters has alleviated the need for modules with specific voltages. When the PV cells are wired together in series, the current output is the same as the single cell, but the voltage output is the sum of each cell voltage, as shown in Figure 4.2.

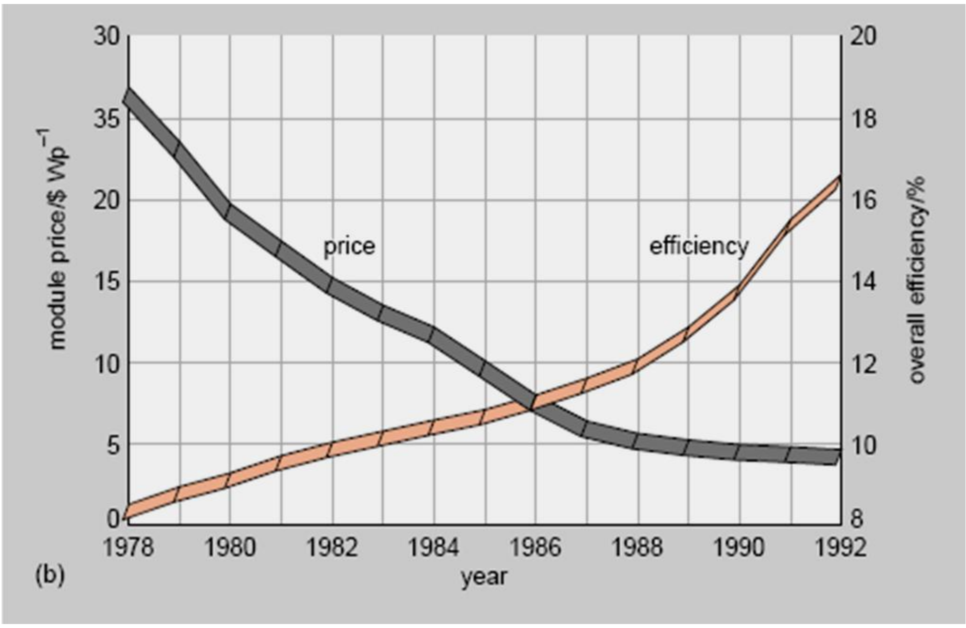


Figure (4.1): Increases in PV module efficiency, and decreases in cost per peak watt, 1978–1992 [26].

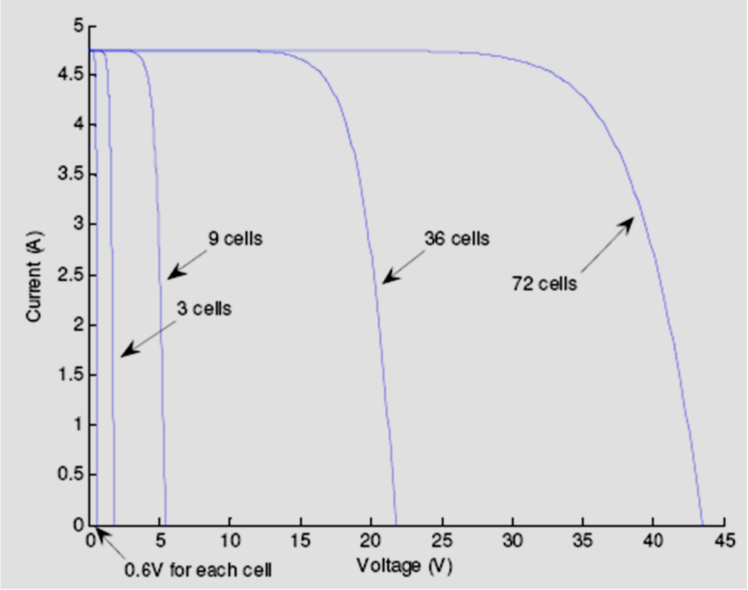


Figure (4.2): PV cells are connected in series to make up a PV module

Also, multiple modules can be wired together in series or parallel to deliver the voltage and current level needed. The group of modules is called an array.

4.2.1 PV Operating Principle

A PV cell is made of at least two layers of semiconductor material. One layer has a positive charge, the other negative.

The photovoltaic effect is the basic physical process through which a PV cell converts sunlight into electricity. Sunlight is composed of photons, or particles of solar energy. These photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons strike a PV cell, they may be reflected or absorbed, or they may pass right through. Only the absorbed photons generate electricity. When this happens, the energy of the photon is transferred to an electron in an atom of the cell (which is actually a semiconductor). With its newfound energy, the electron is able to escape from its normal position associated with that atom to become part of the current in an electrical circuit. By leaving this position, the electron causes a "hole" to form. Special electrical properties of the PV cell—a built-in electric field—provide the voltage needed to drive the current through an external load (such as a light bulb) as shown in figure 4.3.

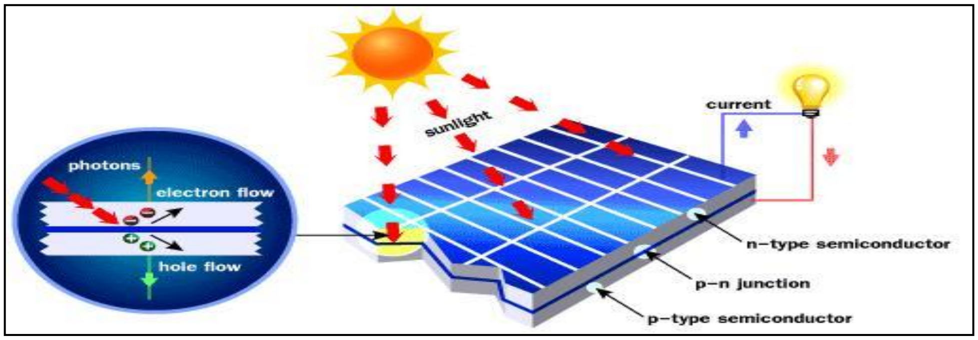


Figure (4.3): Basic solar cell construction

The simplest model of a PV cell is shown as an equivalent circuit below that consists of an ideal current source in parallel with an ideal diode. The current source represents the current generated by photons (often denoted as *Iph* or *IL*), and its output is constant under constant temperature and constant incident radiation of light as shown in figure 4.4.

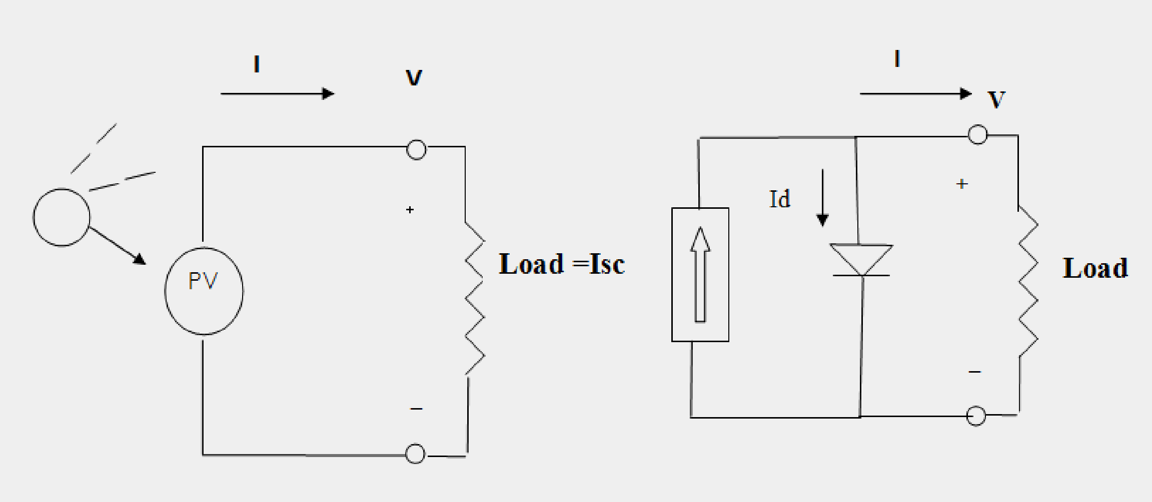
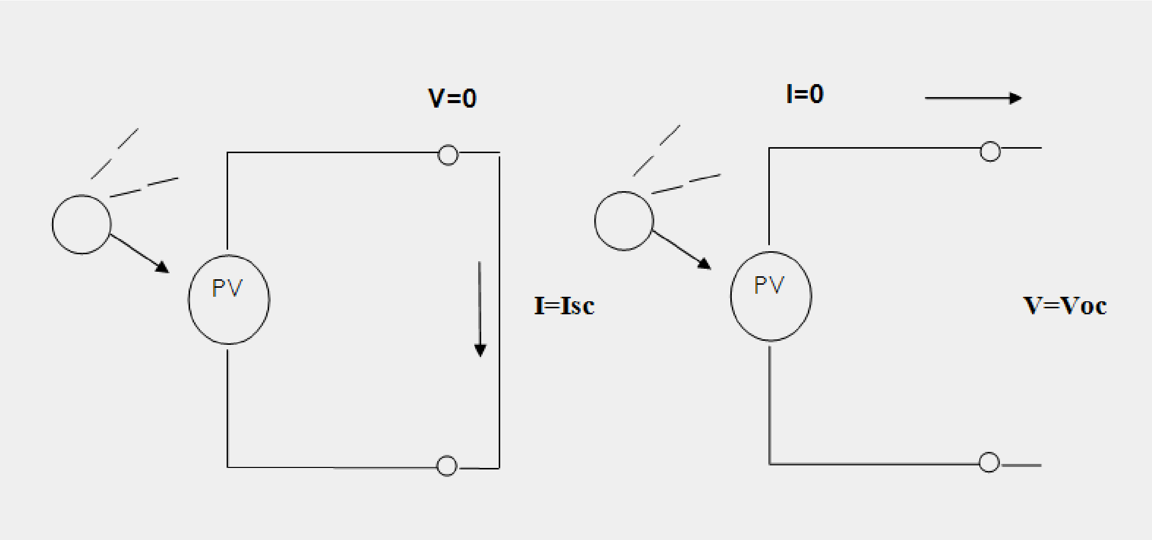


Figure (4.4): PV cell with a load and its simple equivalent circuit [21]

There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, as shown in Figure 4-5 (a), the photon generated current will follow out of the cell as a short-circuit current (*Isc*). Thus, *Iph* = *Isc*. As shown in Figure4-5 (b), when there is no connection to the PV cell (open-circuit), the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage (*Voc*). The PV module or cell manufacturers usually provide the values of these parameters in their datasheets.



(a) Short-circuit current (b) Open-circuit voltage

Figure (4.5): Diagrams showing a short-circuit and an open-circuit condition [21]

The output current (I) from the PV cell is found by applying the Kirchhoff's current law (KCL) on the equivalent circuit shown in Figure 4.4.

$$I = I_{sc} - I_d \qquad (4.1)$$

Where: I_{sc} is the short-circuit current that is equal to the photon generated current, and I_d is the current shunted through the intrinsic diode.

The diode current I_d is given by the Shockley's diode equation:

$$I_d = I_o(e^{qV_d/KT} - 1) \qquad (4.2)$$

Where: I_0 =is the reverse saturation current of diode (A).

q = the electron charge ($1.602X10^{-19}$ °C).

V_d = the voltage across the diode (V).

k = the Boltzmann's constant ($1.381X10^{-23}$ J/K).

T =the junction temperature in Kelvin (K).

Replacing Id of the equation (4.1) by the equation (4.2) gives the current-voltage relationship of the PV cell.

$$I = I_{sc} - I_o(e^{qV/KT} - 1) \qquad (4.3)$$

where: *V* is the voltage across the PV cell, and *I* is the output current from the cell.

The reverse saturation current of diode (I_0) is constant under the constant temperature and found by setting the open-circuit condition as shown in Figure 4.5(b). Using the equation (2.3), let *I* = 0 (no output current) and solve for I_0.

$$0 = I_{sc} - I_o(e^{qV/KT} - 1) \qquad (4.4)$$

$$I_{sc} = I_0(e^{qV/KT} - 1) \qquad (4.5)$$

$$I_0 = \frac{I_{sc}}{(e^{qVoc/KT} - 1)} \qquad (4.6)$$

To a very good approximation, the photon generated current, which is equal to *Isc*, is directly proportional to the irradiance, the intensity of illumination, to PV cell, thus, if the value of I_{sc} is known from the datasheet, under the standard test condition, G_0 =1000W/m^2 at the air mass (*AM*) = 1.5, then the photon generated current at any other irradiance, *G* (W/m^2), is given by:

$$I_{sc}I_G = \left(\frac{G}{G_0}\right) I_{sc0}I_{G0} \qquad (4.7)$$

4.2.2 Standard Test Conditions and I-V Curve

The rated power of a solar cell or a module is basically reported in “peak watts” [W_P] and measured under internationally specified test conditions, namely Standard Test Conditions (STC), which refers to global radiation 1000 W/m² incident perpendicularly on the cell or the module, cell temperature 25 °C and AM 1.5 (AM: air mass).

Photovoltaic modules have current voltage relationship which is represented in I-V curve as shown in figure 4.6.

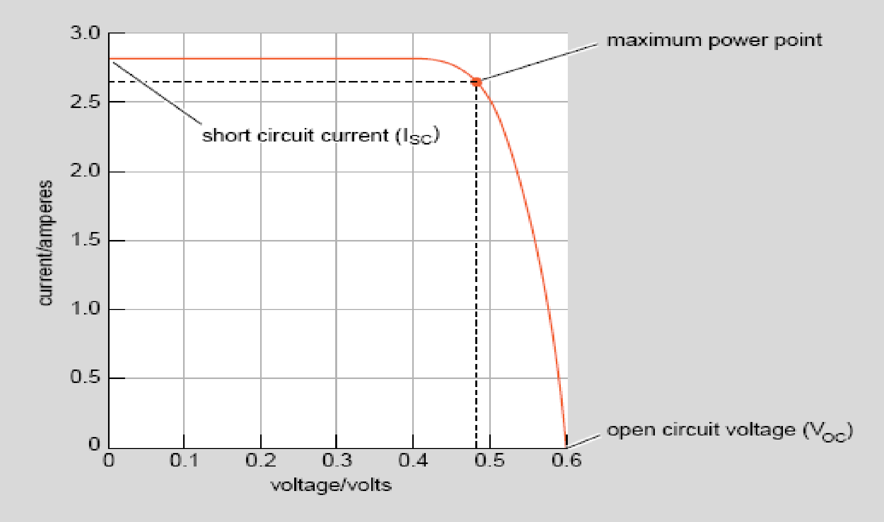


Figure (4.6): (I-V) Characteristics of a typical silicon PV cell under standard test conditions.

Main PV cell type

Crystalline silicon

By far, the most prevalent *bulk* material for solar cells is crystalline silicon (abbreviated as a Group as *c-Si*), also known as "solar grade silicon". Bulk silicon is separated into multiple Categories according to crystallinity and crystal size in the resulting ingot, ribbon, or wafer.

1. ***Mono crystalline silicon*** (c-Si): often made using the Czochralski process. Single-crystal wafer cells tend to be expensive, and because they are cut from cylindrical ingots, do not completely cover a square solar cell module without a substantial waste of refined silicon. Hence most *c-Si* panels have uncovered gaps at the four corners of the cells.η=(10-15)%

2. ***Poly- or multi crystalline silicon*** (poly-Si or mc-Si): made from cast square ingots large blocks of molten silicon carefully cooled and solidified. Poly-Si cells are less expensive to produce than single crystal silicon cells, but are less efficient. US DOE data shows that there were a higher number of multi crystalline sales than mono crystalline silicon sales. η=10%.

3. ***Ribbon silicon*** is a type of multi crystalline silicon: it is formed by drawing flat thin films from molten silicon and results in a multi crystalline structure. These cells have lower efficiencies than poly-Si, but save on production costs due to a great reduction in silicon waste, as this approach does not require sawing from ingots.

Thin films

The various *thin-film* technologies currently being developed reduce the amount (or mass) of light absorbing material required in creating a *solar cell*. This can lead to reduced processing costs from that of bulk materials (in the case of silicon thin films) but also tends to reduce *energy conversion efficiency* average 7 to 10% efficiency), although many multi-layer thin films have efficiencies above those of bulk silicon wafers.

They have become popular compared to wafer silicon due to lower costs and advantages including flexibility, lighter weights, and ease of integration.

- ## Cadmium telluride solar cell

A cadmium telluride solar cell is a solar cell based on cadmium telluride, an efficient light-absorbing material for thin-film cells. Compared to other thin-film materials, CdTe is easier to deposit and more suitable for large-scale production.

There has been much discussion of the toxicity of CdTe-based solar cells. The perception of the toxicity of CdTe is based on the toxicity of elemental cadmium, a heavy metal that is a cumulative poison. While the toxicity of CdTe is presently under debate, it has been shown that the release of cadmium to the atmosphere is impossible during normal operation of the cells and is unlikely during fires in residential roofs. Furthermore, a square meter of CdTe contains approximately the same amount of Cd as a single C cell Nickel-cadmium battery, in a more stable and less soluble form.

Copper-Indium Selenide

The materials based on $CuInSe_2$ that are of interest for photovoltaic applications include several elements from groups I, III and VI in the periodic table. These semiconductors are especially attractive for thin film solar cell application because of their high optical absorption coefficients and versatile optical and electrical characteristics which can in principle be manipulated and tuned for a specific need in a given device.

CIS is an abbreviation for general chalcopyrite films of copper indium selenide (**C**u**I**n**S**e_2), CIGS mentioned below is a variation of CIS. CIS films (no Ga) achieved greater than 14% efficiency. However, manufacturing costs of CIS solar cells at present are high when compared with amorphous silicon solar cells but continuing work is leading to more cost-effective production processes. The first large-scale production of CIS modules was started in 2006 in Germany by Würth Solar. Manufacturing techniques vary and include the use of Ultrasonic Nozzles for material deposition. Electro-Plating in other efficient technology to apply the CI(G)S layer.

- ## Gallium arsenide multi junction

High-efficiency multi junction cells were originally developed for special applications such as satellites and space exploration, but at present, their use in terrestrial concentrators might be the lowest cost alternative in terms of $/kWh and $/W.[37] These multi junction cells consist of multiple thin films produced using metalorganic vapour phase epitaxy. A triple-junction cell, for example, may consist of the semiconductors: GaAs, Ge, and $GaInP_2$. Each type of semiconductor will have a characteristic band gap energy which, loosely speaking, causes it to absorb light most efficiently at a certain color, or more precisely, to absorb electromagnetic radiation over a portion of the spectrum. The semiconductors are carefully chosen to absorb nearly all of the solar spectrum, thus generating electricity from as much of the solar energy as possible.

4.2.3 Effect of Solar Radiation on PV Performance

For several solar radiation varies between 200 to 1000 W/m² and for a constant temperature equal to 25 °C, we have presented the characteristic I_{pv} = f (V_{pv}) and the P_{pv} =f (V_{pv}) of PV generator, the variations versus the solar radiation of the maximal output PV generator power, and the global efficiency of the PV system as shown in figure 4.7 and figure 4.8.

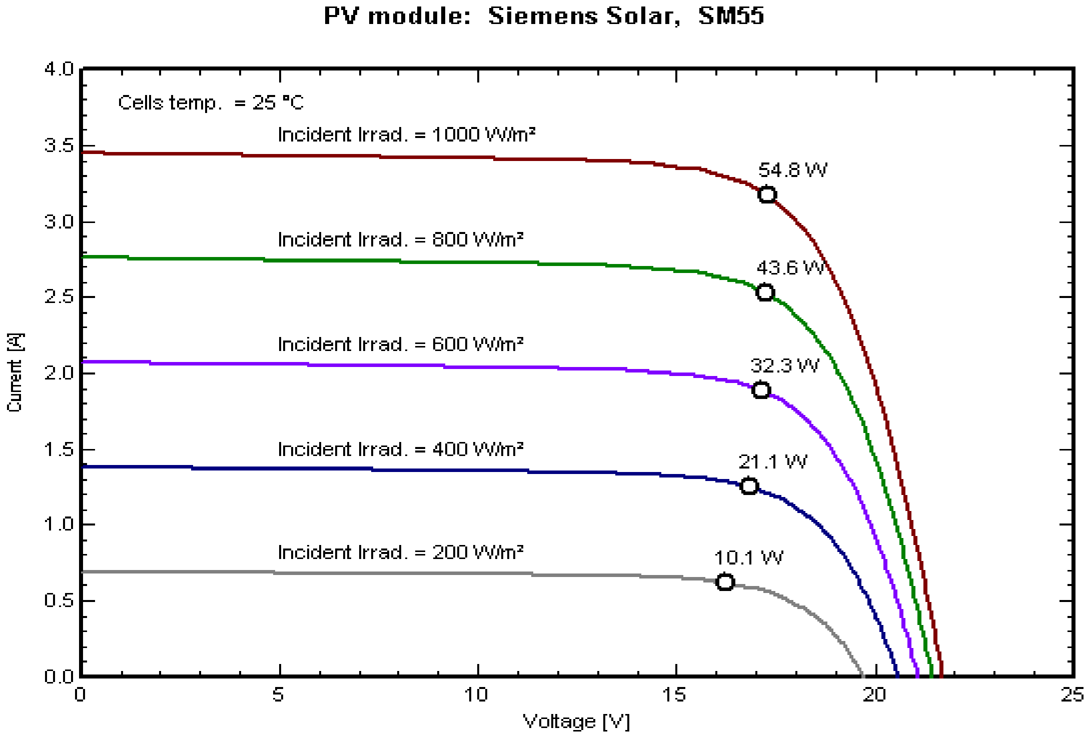


Figure (4.7): PV module (I-V) curve with variation of solar radiation and constant temperature [27].

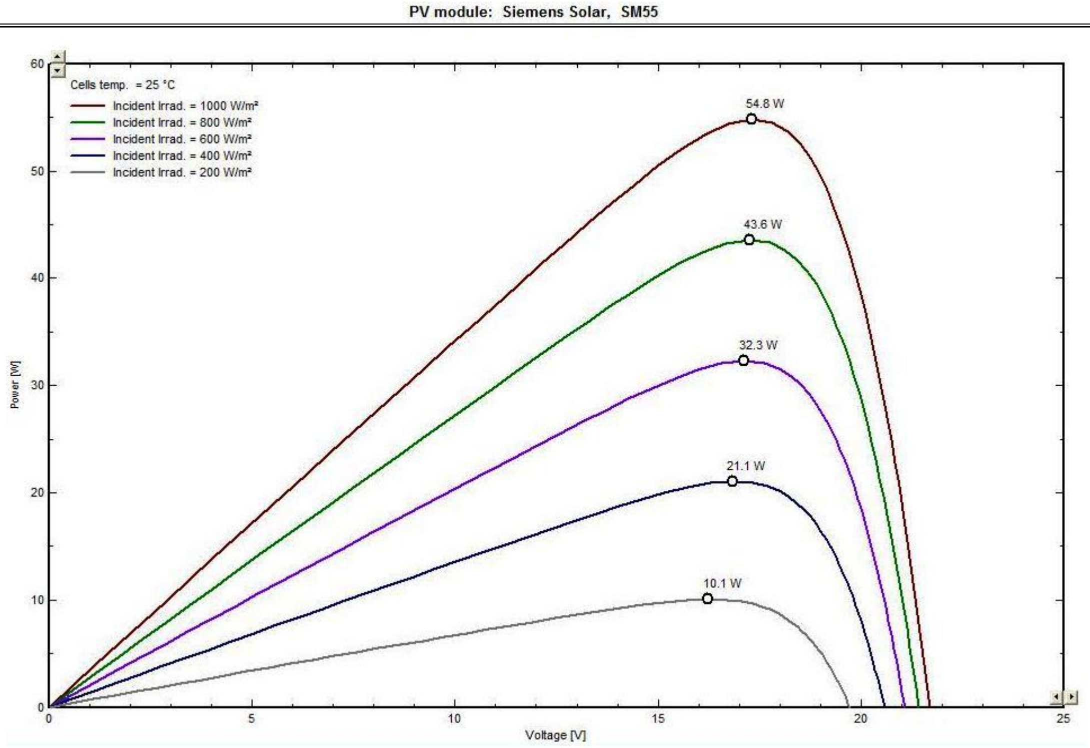


Figure (4.8): PV module (P-V) curve with variation of solar radiation and constant temperature [27].

4.2.4 Effect of Temperature on PV Performance

As known, meteorological parameters, especially the array temperature do not remain constant all day long, but change considerably. It is then worth investigating the influence of the daily average temperature variation on the performances of the optimized system. For several temperature data between 5 and 75 °C and constant solar radiation equal to 1000 W/m².

Figure 4.9 and figure 4.10 display the simulation results as a function of temperature, obtained for a constant solar radiation equal to 1000 W/m². As a result, the global PV system efficiency decreases about 0.03 %/°C. The open circuit voltage decreases as the temperature increases.

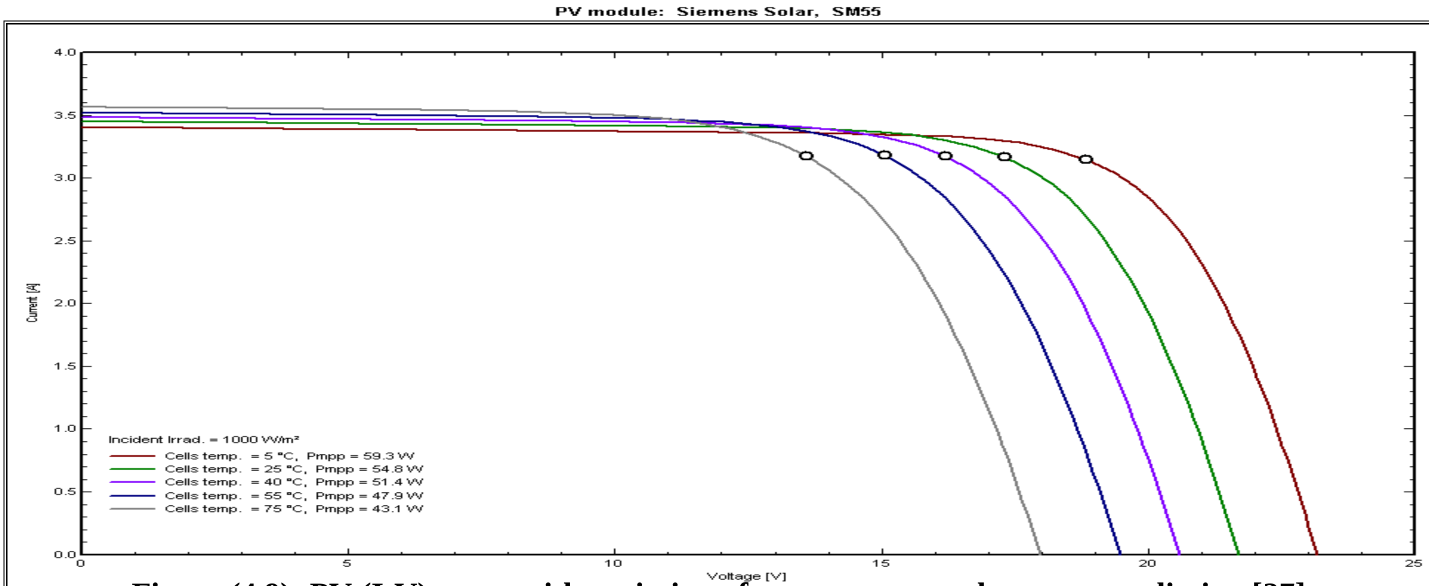


Figure (4.9): PV (I-V) curve with variation of temperature and constant radiation [27].

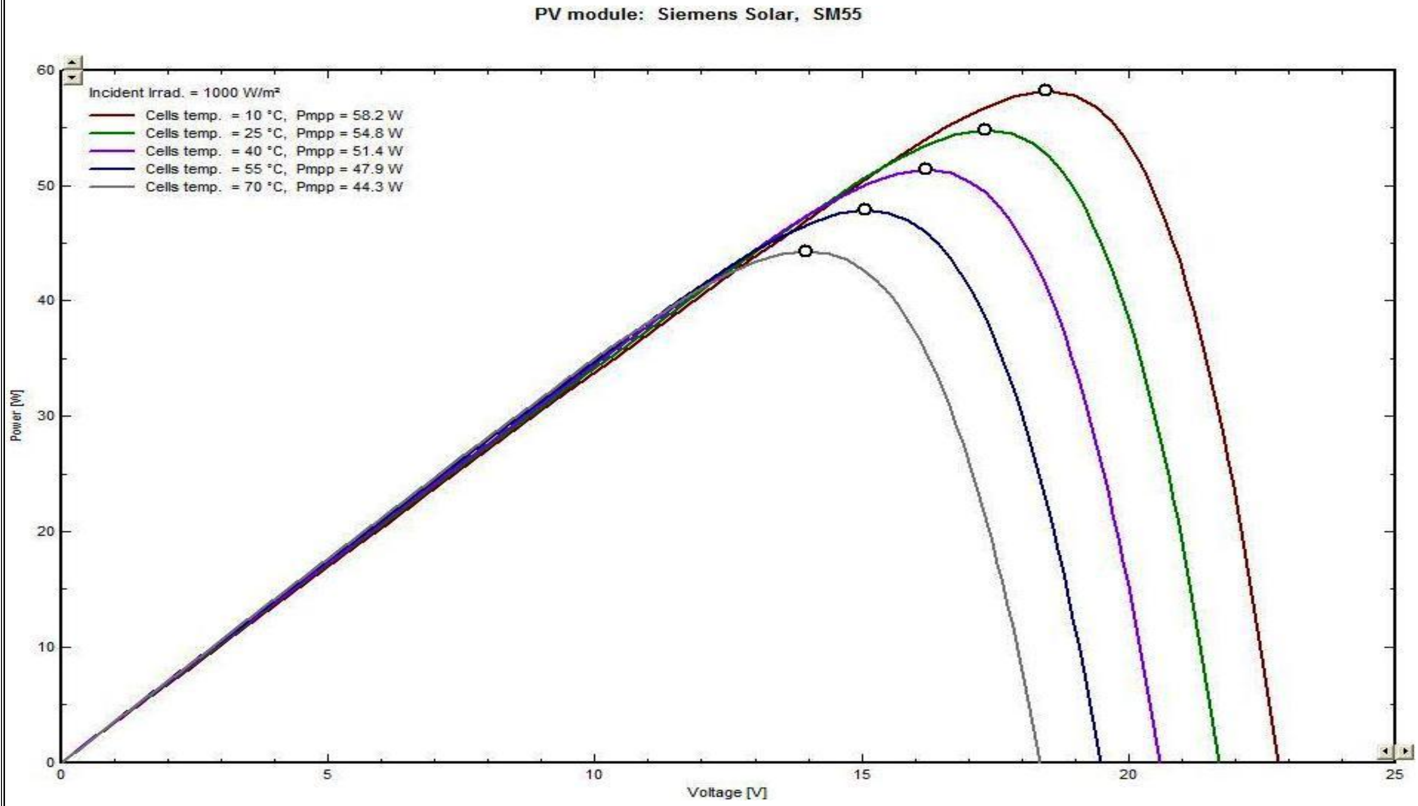


Figure (4.10): PV (P-V) curve with variation of temperature and constant radiation [27].

Normal operating cell temperature (NOCT):

$T_{\mathbf{c}}=T_{\text{ambient}} + [(NOCT - 25) * G] \backslash 800\ W\backslash m^2$

Where, $T_{\mathbf{c}}$ is the cell temperature, G is stander radiation =1000W\m^2

CHAPTER FIVE

EXPERIMENTAL WORKS

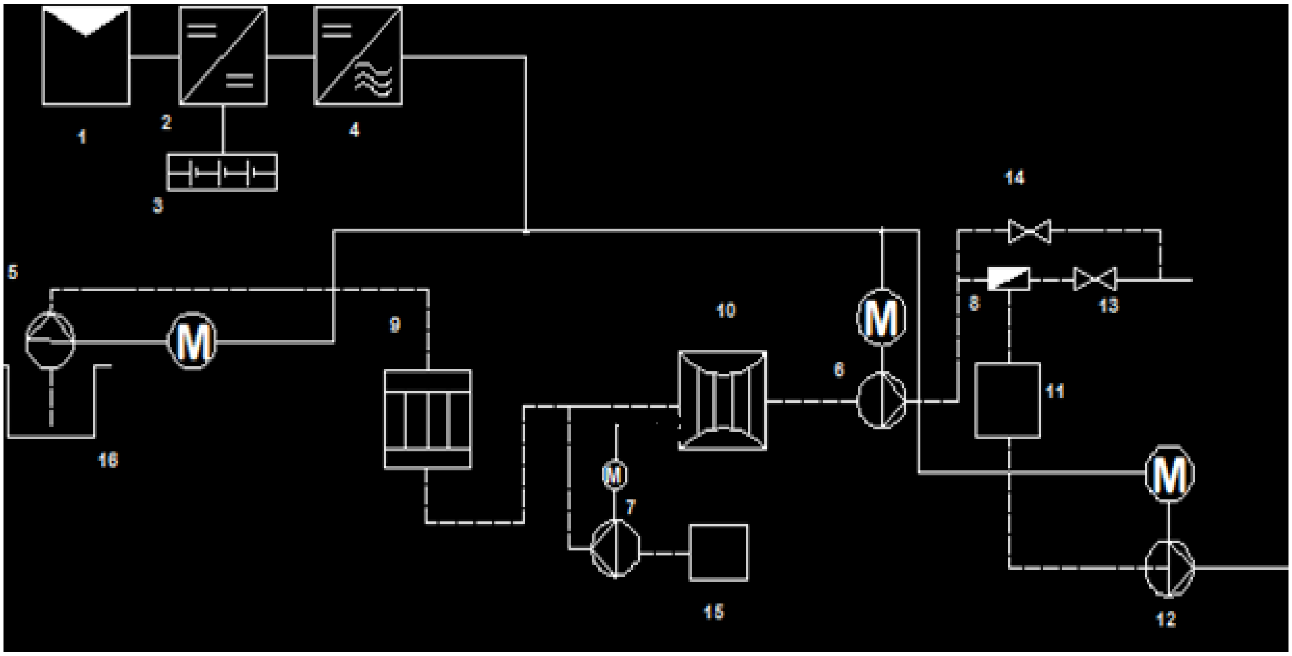
CHAPTER FIVE

EXPERIMENTAL WORKS

5.1 System configuration

The construction of the proposed RO plant is illustrated in figure below .The brackish water is Fed by the well pump in to the raw water storage tank. Before entering the desalination system, The raw water passes a sand filter and cartridge filter to remove excess turbidity or suspended Solids, which may cause problems in pump operation and instrumentation if they enter the RO System. They may block the flow passage or deposit on the membrane surfaces causing changes In product water and salinity.

The RO- modules are served by high pressure piston pumps of 1000 liters \h capacity at 7.7 bars. The feed water is distributed across the membranes by means of transverse stream filtration and By this apart of the water is desalinated as it permeates the membranes. The remaining brine is Drained off. The pure water flows from the modules to a storage tank. The operating pressure is Adjusted by manually operated valves the product water is stored in intermediate tank. This Potable water will be pumped to other storage tank where it can be chlorinated to prevent Bacterial contamination.



1-Solar Generator.   2- DC\DC Convertor.   3- Battery Block. 4-DC\AC Three Phase Inverter.

5- Transfer Pump.   6- High pressure pump. 7- Anti.Scalent pump.   8- RO Module.

9- Multi Media-Sand filter.   10-Cartridge Filter.   11- Product Water Storage.

12- Product Water pumps.   13- Regulator Valves.   14-Starting Valves.

15- Chemical Tank.   16- Water Well.

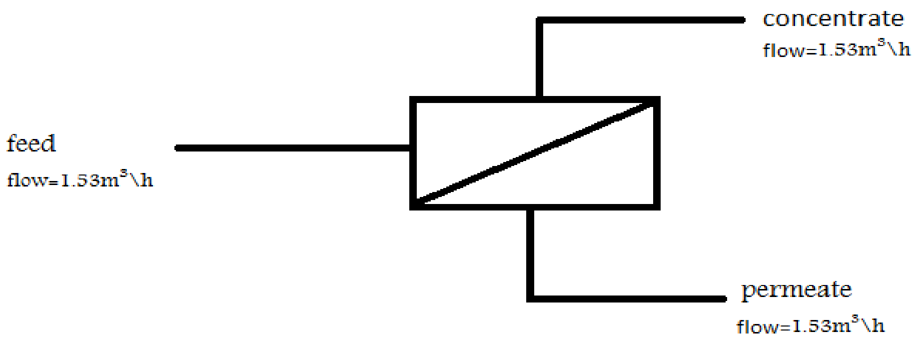
5.2 Design Steps:

First: we enter the feed water data (ions (mg\l)) from Zbaidat tank into ROSA program:

Name	Feed(mg\l)
NH4	**0.00**
K	**13.10**
Na	**483.00**
Mg	**146.00**
Ca	**200.00**
Sr	**0.00**
Ba	**0.00**
CO3	**1.81**
HCO3	**305.00**
Cl	**36.00**
F	**0.00**
SO4	**157.00**
SiO2	**21.60**
Boron	**0.46**
CO2	**7.85**
TDS	**2566.15**
pH	**7.60**

Then, we specify the feature of operation as:

- Recovery =65%.
- Feed flow=1.53 m^3\h.
- Permeate flow=1.0 m^3\h.
- Operating temperature =25° C.
- One stage in pass.
- Operating time =10 h\day.



After that we will see ROSA system simulation as:

System Details

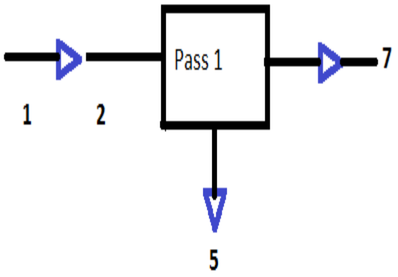
Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed	Concentrate	Permeate	
			Stage 1	Stage 1	Total
NH4	0.00	0.00	0.00	0.00	0.00
K	13.10	13.10	30.46	3.90	3.90
Na	483.00	483.00	1347.50	24.81	24.81
Mg	146.00	146.00	413.82	4.05	4.05
Ca	200.00	200.00	567.12	5.42	5.42
Sr	0.00	0.00	0.00	0.00	0.00
Ba	0.00	0.00	0.00	0.00	0.00
CO3	1.81	1.81	13.34	0.00	0.00
HCO3	305.00	305.00	834.83	15.50	15.50
NO3	36.00	36.00	75.56	15.03	15.03
Cl	1200.00	1220.36	3440.50	43.67	43.67
F	0.00	0.00	0.00	0.00	0.00
SO4	157.00	157.00	448.24	2.64	2.64
SiO2	21.60	21.60	61.25	0.58	0.58
Boron	0.46	0.46	0.59	0.39	0.39
CO2	7.85	7.84	12.00	8.75	8.75
TDS	2566.15	2586.51	7236.03	117.84	117.84
pH	7.60	7.60	7.76	6.41	6.41

Pass #	**Pass 1**
Stage #	**1**
Element Type	LE-4040
Pressure Vessels per Stage	1
Elements per Pressure Vessel	8
Total Number of Elements	8
Pass Average Flux	17.25 lmh
Stage Average Flux	17.25 lmh
Permeate Back Pressure	1.00 bar
Booster Pressure	0.00 bar
Chemical Dose	-
Energy Consumption	0.79 kWh/m^3

Pass 1

Stream #	**Flow (m^3/h)**	**Pressure (bar)**	**TDS (mg/l)**
1	1.53	0.00	2566.15
3	1.53	7.77	2586.51
5	0.53	6.93	7236.03
7	1.00	-	117.84
7/1	**% Recovery**	65.36	



After this simulation we obtain the output power of the motor equal to 0.8 KW\m^3

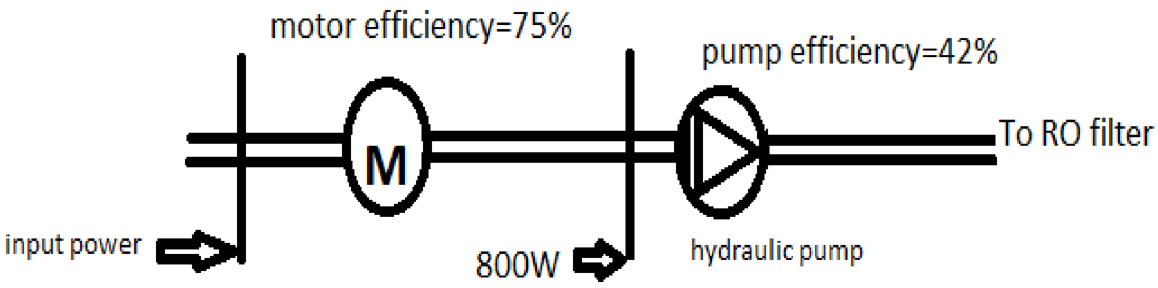
From this point we start calculating elements power as follow:

- ***Hydraulic pump calculation*** :

- Efficiency (ɳ)= output Power \ input power
- Power input $_{\text{Hydraulic}}$ = 800*0.42 =36 W
- Power input $_{\text{motor}}$ = 800 \ 0.75 =1066.6 W

If we take safety factor about 20%, then:

- Actual Power $_{\text{for motor}}$ = 1279.2 W , we will take it equal 1300W
- Pump specification: 1.694m^3\h at 88.36m (from ROSA program).



- ***Transfers pump calculation***:

- Pump specification: 2.5 m^3\h at 3.79 bar

2.5 m^3\h at 38.63 m Head

- Power output $_{\text{Hydraulic}}$ = 2.725*2.5*38.63 = 263.19W
- Power input $_{\text{transfer pump}}$= 263.19 \ 0.42 = 626.6 W
- Power input $_{\text{motor}}$ = 626.6 \ 0.75 =835.5 W

- ***Anti scalent pump calculation***:

- Its small pump, single phase so we choose its power equal to 250W.

System over view:

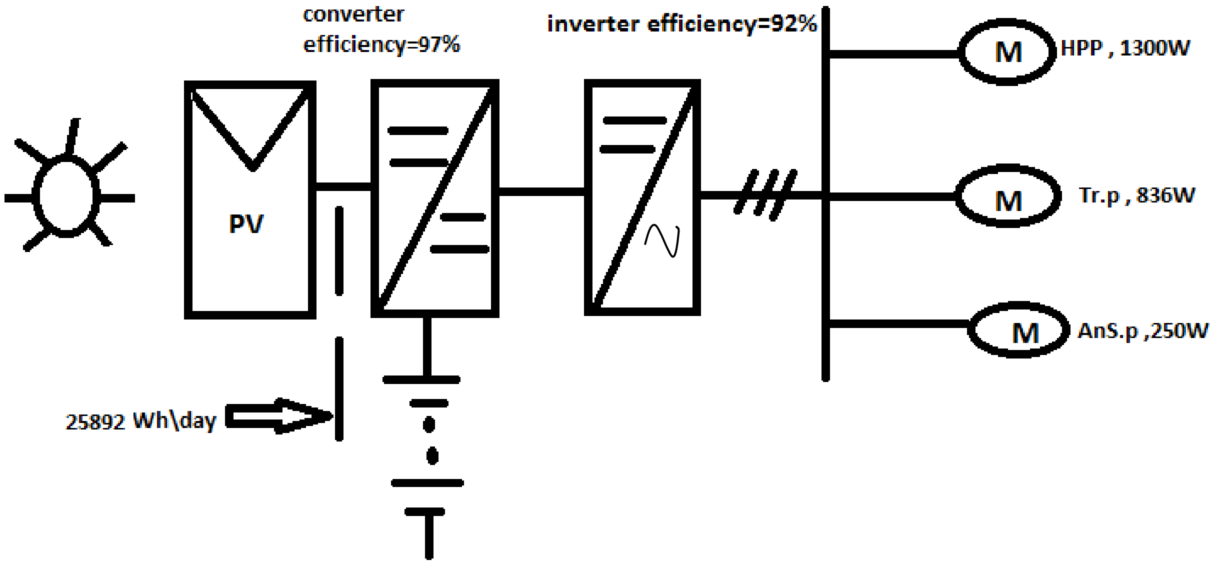


Figure 1

❖ Sizing of the PV generator :

The most appropriate PV power system to cover such a load is illustrated in figure 1.The peak power of the PV generator Power$_{PV}$ is obtained as follow:

Power$_{PV}$ = Ed \ ɳv * ɳr *PSH

Where,

Ed: daily energy consumption =2511.6 Wh\day.

Peak sun hours (PSH) =5400 \ 1000 =5.4 hours \ day.

ɳv: efficiency of inverter =95%.

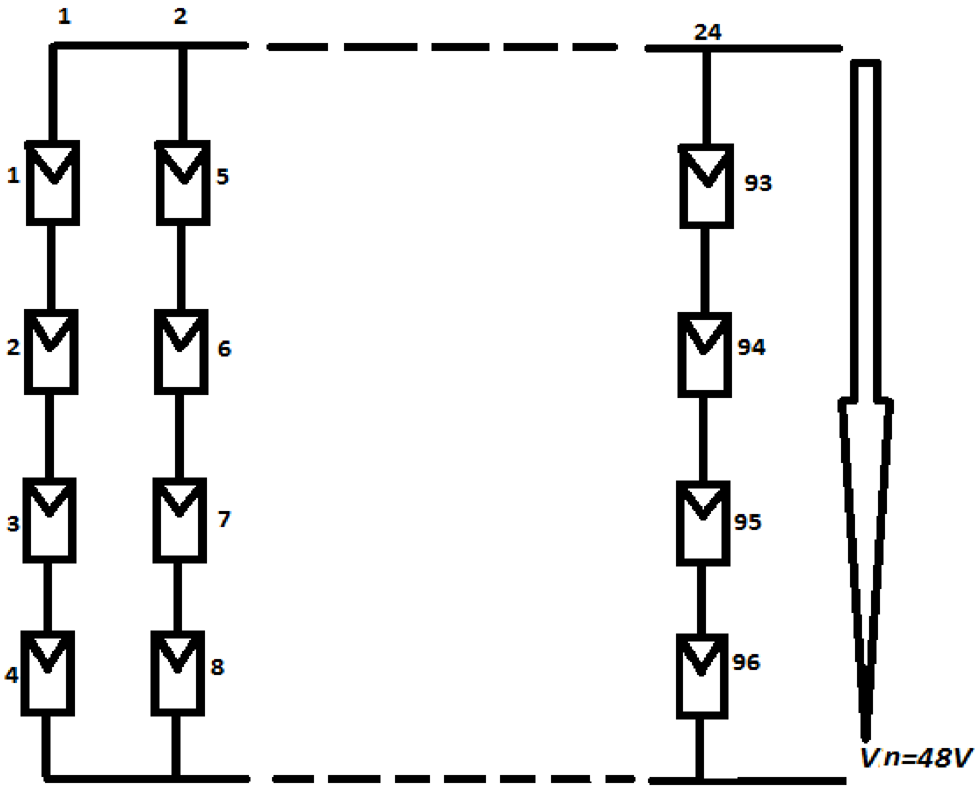
ɳr: efficiency of convertor =97%.

Power$_{PV}$ = [(1300+836+250)\0.95] Wh \ 5.4Wh =4795 Wp.

To install this power, amono-crystalline PV module type SM55 of across area of $A_{pv} = 0.4267 m^2$

Rated at 12 VDC and a peak power of 50Wp are selected. The number of the necessary PV modules ($N_{pv\ module}$) is obtained as:

- $N_{pv\ module} = P_{pv} \backslash P_{mpp}$.
- $N_{pv\ module} = 4795 \backslash 50 = 96$.
- $P_{pv\ actual} = 96*50 = 4800Wp = 4.8\ KWp$.



PV Generator

❖ Sizing the battery block :

The storage capacity of battery block for such system is considerable large. Therefore, special Lead-acid battery cells (block type) of long life time (larger than 10years), high cycling stability Rate (>1000times) and capability of standing very deep discharge should be selected. Such Battery types are available but at much higher price than regulator batteries. The ampere hour Capacity (C_{Ah}) and watt hour capacity (C_{wh}) of the battery block, necessary to cover the load Demands for a period of 1 day without sun, is obtained as follow:

$C_{Ah} = E_d \backslash \eta_{battery} * DOD * V_B$

$C_{wh} = C_{Ah} * V_B$

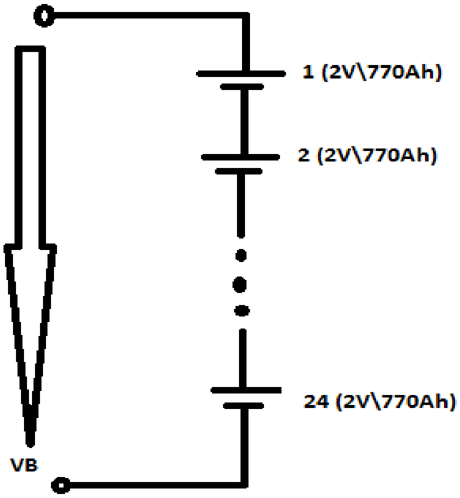
Where, $\eta_{battery}$ and VB $_{are}$ the efficiency and voltage of battery block, while DOD is the Permissible depth of discharged rate of the cell. Assuming realistic value of $\eta_{battery}$ =85% DOD=80% and V_B =48V, we obtain:

$C_{Ah} = 2511.6\ Wh \backslash 0.85 * 0.8 * 48$

$C_{Ah} = 770\ Ah$.

$C_{wh} = 770 * 2 = 1540Wh = 1.54\ KWh \backslash cell.$

$C_{wh\ total} = 1.54 * 24 = 36.96\ KWh.$



Storage battary block

❖ **The charge regulator and inverter** :

The charge regulator (CR) is necessary to protect the battery block against deep discharge and Over charge. Input\output rating of charge regulator are fixed by the output of the PV array and V_B. In this case the appropriate rated power of CR is 5 KW with maximum power tracking. The Input of inverter have to be match with the battery block voltage so the appropriate rated power Is 3.2 KW, 3.8 KVA (non sinusoidal).

CHAPTER SIX

ECONOMIC EVALUATION OF RO UNIT POWERED BY PV SYSTEM

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6.1 Cost Analysis

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

The product cost is strongly correlated with unit capacity, quality of feed water, pretreatment, types of water treatment technology, site condition, costs of land and additional costs.

In order to establish the absolute or relative acceptability of an investment, we can use two different procedures, the static method and the dynamic method.

They differ from each other in the sense that the dynamic method takes into account the different times at which payments on an investment are receivable.

Therefore, by using dynamic procedures, receipts and payment are given higher value the earlier they fall and lower value later.

Because of this time component in evaluating investment linked payments, the dynamic method produce undoubtedly better results than the static method.

Dynamic method:

1- Cost annuity (cost annuity per production unit).

2- Net present value.

First: Cost annuity

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:

- Plant life time is 20 years.
- Operating days per year are 365 days.
- Operating and maintenance (O&M) costs are 20% of the system annual payment.
- Annual rate of membrane replacement is 20%.
- Interest rate is 8%.
- Plant availability (f) is 100%
- Capacity(M)=10m^3/day
- Salvage value of the units will be zero.

6.1.1 Capital Cost

A detailed cost analysis of the system has been completed and is summarized below:

No	Component, material or work.	quantity	Unit price ($)	Total price ($)
1	PV module	4800 Wp	2.9	13920
2	Support structure for PV			3800
3	Converter (5KW)	1	3500	3500
4	Inverter (3.8KVA,3.2KW)	1	2200	2200
5	Batteries (36.96KWH)			9240
6	HPP(1300W)	1	1500	1500
7	Tr-P(836W)	1	1000	1000
8	Ans-P(250W)	1	3000	3000
9	RO Membranes	8	2700	21600
10	Multimedia fitter	1	1200	1200

11	Cartridge filter	1	1000	1000
12	Piping (stanless steel)			1200
13	Valves(stanless steel)			600
14	Fresh water pump	1	400	400
15	Chemicals tank	1	100	100
16	Fresh water tank	1	250	250
17	Installation material and other accessories			2200
18	Civil works			2000
Total system cost				68710$

6.1.2 Annual Operating Costs

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

6.1.2.1 Fixed Charges

To determine the fixed charge value of the capital costs, these costs are multiplied by an amortization factor (*a*)

The fixed charges factor is a function of the interest rate(i) which is value 8% of the capital and the numbers of years over which the investment is recovered which is value 20 years. The fixed charges factor can be calculated using the following relationship.

$$\boxed{a = \frac{i(1+i)^n}{(1+i)^n - 1}}$$

Where *i* is the interest rate of the amortized investment (%) and *n* is the period of repayment of capital expenditures (life time).

$$a = \frac{i(1+i)^n}{(1+i)^n - 1}$$

$$a = \frac{0.08(1+0.08)^{20}}{(1+0.08)^{20} - 1}$$

$$a = 0.102$$

- **Annual fixed charges (A_{fixed}):**

$\boxed{A_{fixed} = \text{(a) X (Capital Cost)}}$

A_{fixed} = 0.102X68710$ =7008.4$/year

6.1.2.2 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.

- **Annual operating and maintenance costs (*AO&M*)**

$$\boxed{A_{o\&m} = (20\%) \times (A_{fixed})}$$

$A_{o\&m}$ = (20%) X (7008.4) \$/year=1401.68\$/year

6.1.2.3 Membrane Replacement

The success of an RO system depends upon membrane life and performance Membranes lose performance and are replaced due to raw water quality, the deposition of unwanted materials on the surface. In addition, a decrease in membrane performance may be due to other factors, i.e., degradation by chemical (oxidation, hydrolysis).

Replacement rate may vary between 5%–20% per year.

- **Annual membrane replacement costs ($A_{replacement}$):**

$$\boxed{A_{replacement} = (20\%) \times (\text{Membrane Cost})}$$

$A_{replacement}$ = (20%) X21600\$=4320\$/Year

- **Total annual cost (A_{total})**

$$\boxed{A_{total} = A_{fixed} + A_{replacement} + A_{o\&m}}$$

A_{total} =7008.4\$/year+4320\$/Year+1401.6\$/year=12730\$/year

- **Unit production cost (A_{unit})**

$$\boxed{A_{unit} = \frac{(A_{total})}{(f)(M)(300)}}$$

$$A_{unit} = \frac{12730\$ / year}{(100\% \times 10m^3 / day)(365day / year)}$$

A_{unit} =3.5\$/m³

6.2 Life Cycle Cost

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

1. The life cycle of the system components will be considered as 20years.
2. The interest rate is about 8%.

The initial cost of the system = 68710$

The annual maintenance and operation cost is about 20% of initial cost which is equal 13742$/year, salvage value of the system will be zero.

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

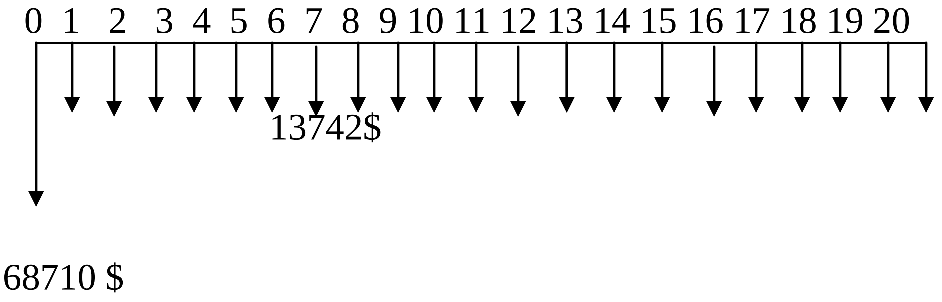

Figure1: Cash flow of units

To calculate the equivalent uniform annual series A of cash flow in figure1 which include randomly placed single amounts and uniform series amounts, the most important fact to remember is to first convert everything to a present worth or future worth. Then the equivalent uniform series is obtained with appropriate A/P or A/F factors.

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 = 68710\$ + 13742 $(P/A_{i,n})$ - 0

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad i \neq 0$$

P = A (9.82)

$(P/A_{i,n}) = 9.82$

PW= 68710\$ + 13742 X 9.82=203656.44\$

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

AW = PW (A/P $_{i,n}$) =203653.44$ (A/P $_{10\%,25}$).

A = P $\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$ i≠0

A=P (0.102)

(A/P $_{10\%,25}$) =0.102

AW= PW (A/P $_{i,n}$) =203656.44$ X0.102=20772.95$

Energy consumption/year= average yearly power consumption/day X operating hours. =2386WX10h X365 days

=8708.9KWh/year

The cost of 1 KWh from the PV generator (cost annuity)=20772.95$/8708.9KWh

= 2.38$/KWh.

6.3 **Net Present Value**

Net Present Value and the Tariff For a project to be profitable the NPV must have appositive value .The greater the NPV the more profitable is the system.

Tariff: is the rate at which electrical energy is supplied to a consumer.

Assuming certain tariff ($\KWh), the total annual revenue (ART) as a result of energy sold can be calculated using the following equation:

ART= Tariff * ELT

Where ELT: energy required for the load

NPV = (PWFC *ART) - LCC

Where: LCC: is the life cycle cost, PWFC: cumulative present worth factor

PWFC $=\frac{1-X^{n}}{1-X}$

X = 1+i /1+d

d:discount rate 8%

i: inflation rate (measure of decline in value of money) 5%

X=1+10% / 1+8% =1.018

PWFC=24

ART=2.38$\KWh * 8708.9KWh= 20745.7$

LCC = 203656.44$

NPV = (24* 20745.7) – 203656.44 =294240 > 0

➡ ***Then the project is profitable***.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

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CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

- the tank capacity =10000 liter\day ,and the daily person needs of fresh water only for drinking = 4 liter\day ,so this tank enough for 2500 person.
- Palestine has very rich solar radiation intensity. The average annual daily solar radiation ranges 5 kWh/m^2.day which provides the optimal option to generate the energy demand for small water treatment units in remote areas.

The combination between renewable energies specially (photovoltaic cells) and RO Water Treatment Processes very suitable in Palestine for remote sites lacking of electric grids where water scarcity is a big problem and, at the same time, the solar energy potential is high.

- The pressure output of the pump exit is directly proportional to the power input to the pump and the power received from the solar panel is also directly proportional to the solar irradiation.

- The rate of production of fresh water by using a photovoltaic-powered household RO unit without storage batteries under different operating conditions, varied throughout the day according to the available solar power.

- The effect of operating parameters on the reverse osmosis membrane performance was investigated. It was found that increasing the solar radiation, pump pressure, and feed water temperature has enhanced the permeate flux. Increasing the TDS, on the other hand, has reduced the permeate flux, and the water quality was within the international standard to be safe drinking water.

- The effect on product quality is generally a very small change compared to the Change observed in productivity when the feed temperature increased from 33°C to 44°C.

- Reverse osmosis membrane is highly effective in removing low total dissolved solids (TDS) from water at low pressures.

- Economically, it was found that although the energy is free, the water production cost from the PV–RO unit is 3.5$/m^3 which is cheap and economically viable, in remote areas and far from conventional energy sources compared to water produced from plants that run on grid electricity.

- It is not economical or practical to provide all energy with PV modules because the solar radiation in the main three winter months is low. Large number of PV modules would be in this case required to meet load requirements for 24h/day. This issue will increase the initial investment cost and will increase the waste or dumped energy in summer where the solar radiation is high.

- One source of renewable energy was not economically viable and could be used as another source assistant as hybrid system which is economical and available for 24h/day along the year.

6.2. Recommendations

- Other sources of water with different characteristics can be also tested. The effect of fecal concentration can be investigated by changing the source of water.
- Different membrane arrangement such series and parallel configurations can be also tested to see the effect of recovery.
- Design of solar heaters that can heat the feed water prior to membrane treatment is highly recommended.

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