Palestine Polytechnic University

College of Engineering and Technology
Mechanical Engineering Department

Graduation Project

Description and Selection of a Desalination System Based on Combining Solar Energy with Membrane Module Technology

Project Team

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Palestine Polytechnic University
(PPU)

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According to the project supervisor and according to the agreement of the testing committee members, this project is submitted to the Department of Mechanical Engineering at college of engineering and technology in partial fulfillment of the requirements of the bachelor's degree.

Department Head Signature

Supervisor Signature

الإهداء

....

بعد خمس سنوات من التحصيل العلمي
لكم أيها السادة نهدي مشروعنا
ولأجلكم والوطن الحبيب نهدي عملنا هذا ...
من صميم قلوبنا وجوارحنا ومشاعرنا
من أفكارنا أيضا نهديكم ...
فإليكم...

....

الوالدين ....

لمن عرفتهم طيور الحب وتراب الأرض ورحيقها
لمن كانت وما زالت الجنة تحت أقدامهن
لن نجد الكلمات للتعبير عن مدى معاناتكم لوصولنا هنا
حفظكم الله ورفعكم قدرا وفخرا للامه
لأجلكم نهدي عملنا هذا....

....

الأصدقاء ...

لمن لا يقدرون بأي ثمن...
لان الكلمات تقف وتنحني لكم حبا واحتراما
لأنكم حصيلة حياه لم نكسب منها إلا انتم
نهديكم عملنا هذا....

....

الأحبة ....

لمن دخلوا القلب...أو سيدخلونه
لمن لنا حظ فيهم
لمن تكن المشاعر والأحاسيس لهم الاحترام
لان الاحترام واجب لكم, أحببناكم
فإليكم نهدي عملنا هذا....

الجامعة ....

لمن توجهنا إليها لتوصلنا إلى هذا العمل
لمن كانت حاضنة العلم والعمل
لمن كانت أما دون أن تلد
لك يا أمنا نهدي عملنا هذا...

....

ونهدي عملنا هذا أيضا
للمشرف الدكتور. عماد الخطيب, الذي كان أبا للعلم و عملاقه
للأستاذ المهندس .أيمن عادي, الذي بمساعدته ارتقينا أيضا بهذا العمل
للجنة المناقشة. والتي نعتز بنقاشها ومداخلاتها وآرائها
ولن ننسى دائرة الهندسة الميكانيكية بفروعها, ورئيسها
فلكم جميعا نهدي عملنا هذا..

....

للماضي والحاضر.....
للمستقبل البعيد, والقريب
لكل من نسيناهم هنا... أو تذكرناهم لاحقا
لكل عشاق الأرض والعلم
لك يا فلسطين ويا شعبنا
لك يا امتنا ويا شعوبنا......
لكم نهدي عملنا هذا...

....

وتقبلوا احترامنا , فريق العمل:
هاني علي شتات محمود محمد الشويكي محمد عمر خشان
طارق علي حمايسه محمد يوسف الذيبة
والمشرف د. عماد الخطيب..

مع أصدق أمنياتنا...

Acknowledgement

To begin with our prophet saying that" who" ever does not thank people, he or she would not thank God. So we would like to extend our gratitude to the administration of Palestine Polytechnic University in general, and the administration of the Mechanical Engineering Department in particular. At the same time express our special thanks to the teachers of the university.

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It's our pleasure to thank whoever participated in backing up this project to be a real and successful one.

Hani Ali Shatat
Tareq Ali Khamayseh

Mahmoud Mohammed Shweiki

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Mohammed Ommar Khashan

Abstract

Water and sanitation condition in Gaza Strip and West Bank are facing severe problem in addition to poor conditions of existing municipality infrastructure that adversely affect the local environment, the ecological system and the public health. The lack of power system has, in the past two years, lead to polluting the coastal aquifer, which is the only water resource that Gaza Strip has, with the untreated wastewater and the intruded sea water. Acreative solution is presented by which a local technology could be used in addition to utilizing the available solar energy for providing the proper thermal and electrical energy needed. The proposed solution based on using a reverse osmosis membrane desalination technology operated by solar energy conversion system , The conversion system uses evacuated tubes for providing the thermal energy needed and photovoltaic solar modules for providing the needed electrical power. This project selects a suitable components which based on calculations and design and by using a software simulation program to simplify this calculations.[1]

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List of abbreviations

Abbreviations	Meaning
WHO	World Health Organization
MCM	Million Cubic Meter
MSF	Multi-Stage Flash
MED	Multi-Effect Distillation
MVC	Mechanical Vapor Compression
TVC	Thermal Vapor Compression
RO	Reverse Osmosis
ED	Electrodialysis
TDS	Total Dissolved Solids
CA	Cellulose Acetate
PA	Polyamide
CPF	Concentration Polarization Factor
SR	Salt Rejection
LMTD	log Mean Temperature Difference
ESTIF	European Solar Thermal Industry Federation

List of Symbols

Symbol	Meaning	Unit
R_p	Permeate Recovery Ratio	%
Q_p	permeate Water Flow Rate	kg/s
Q_f	Feed Water Flow Rate	kg/s
ΔP	Hydraulic Pressure Differential Across the Membrane	kPa
$\Delta\pi$	Osmotic Pressure Difference Across the Membrane	kpa
π	Osmotic Pressure	kPa
R	Universal Gas Constant	kPa m^3/kgmol K
SR	The Salt Rejection.	1
T	Temperature	K
W	Work Consumed by the Pump	kj
V	Volume of Permeate Water	m^3
X_f	Feed Salinity	kg/m^3
X_p	Permeate Salinity	kg/m^3
Q_b	Brine Flow Rate	kg/s
X_b	Brine Salinity	kg/m^3
K_w	Water Permeability Coefficient	m^3/m^2. s kPa
P_p	Permeate Hydraulic Pressure	kPa

π_p	Permeate Osmotic Pressure	kPa
P_a	Average Hydraulic Pressure On the Feed Side	kPa
π_a	Average Osmotic Pressure On the Feed Side	kPa
p_f	Hydraulic Pressure of the Feed Stream	kPa
π_f	Osmotic Pressure of the Feed Stream	kPa
p_b	Hydraulic Pressure of the Reject Stream	kPa
π_b	Osmotic Pressure of the Reject Stream	kPa
Ms	Flow Rate of Salt Through the Membrane	kg/s
Ks	Membrane Permeability Coefficient	m^3/m^2 s
A	Membrane Area	m^2
m	Volumetric Flow Rate	m^3/s
U	The Overall Heat Transfer Coefficient	kJ/h-m2 oC,
Ft	Correction Factor	Dimensionless
Cp (t)	Liquid Specific Heat Tube Side	kJ/kg. C^o
Cp (s)	Liquid Specific Heat Shell Side	kJ/kg. C^o
SR	Salt Rejection	$kmol/m^3$

Chapter One 1

Introduction

Contents:

Chapter 1

Introduction

1.1 General Outlook

Water is so strange liquid base upon which life on Earth, where the water founded the civilization founded and growth up and because of the huge increase in population and rising standard of living and industrial and agricultural development, which led to the contamination of water sources and limited, as a result of the lack of fresh water sources Earth emerged problem of the acute shortage of freshwater and has held a number of studies and research on the future status of water and the search for new water sources non-traditional sources such as, for example, water desalination, especially as we know the population of Palestine that water resources limited and under control by" Israel" side, therefore we supposed to do the necessary studies and research in how to make use of sea and brackish water around us.

1.2 Project Objectives

1. To compensate for the shortfall in sources of fresh water in Palestine.
2. Economic benefit by use of renewable energy sources (like solar energy) rather than the use of non-renewable sources such as fuel, or costly sources such as electric power.
3. To build a water desalination unit based on solar energy as a source of thermal energy and electric power.
4. To increase the available quantity of potable water to consumers.
5. To reduce the over-pumping from the groundwater.

1.3 Connections between the Project and local industry

This project is oriented basically towards local industry and Ministry of Water, which gives information about the ability of production of fresh water. This project supports local industry from these sides:

1. Financial benefits from producing a fresh water using solar energy instead of non-renewable energy.
2. Provide opportunities for industrial investments in building desalination plants.
3. Develop policies required for health and environment protection in addition to encouragement and support local industry.

1.4 Project Schedule

Table 1.1 Project Time-Schedule for First Semester.

process	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Choosing project	▨														
Collecting Data and Literature	▨	▨	▨	▨	▨	▨	▨	▨							
Analyzing of data						▨	▨	▨	▨						
Analysis the Components of Desalination System						▨	▨	▨	▨	▨					
Conclusion										▨	▨				
Writing The documentation and presentation							▨	▨	▨	▨	▨	▨	▨	▨	▨

Table 1.2 Project Time-Schedule for Second Semester.

process	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Design the system	▨	▨	▨	▨	▨	▨									
Select the evacuated tube and pv							▨	▨	▨	▨	▨				
Choosing pumps								▨	▨	▨	▨				
Select the membrane										▨	▨	▨			
Writing Documentation							▨	▨	▨	▨	▨	▨	▨	▨	▨

1.5 Project Budged

Table 1.3 Project Budged

Budget of Desalination System Component

Element	Commercial code	Price
Membrane Module	SW30-2540	$ 400
Evacuated Tube	EN12975	$ 3000
PV panel	KC200GT	$ 5250
Inverter	Sunny Boy Inverter 1800U SBD with LCD	$ 2550
Electrical wire	AWG3-2	$60
Pipes With Insulation	T5180	$ 250
Pipes Without Insulation	T511210	$ 150
Fittings With Insulation	PF38058T2	$ 7.5
Fittings Without Insulation	510-305BG	$ 10
Pump A,B,C,D	S-3220-E	$ 3600
Pump E,F	073831	$687.10
Heat Exchanger	G20090608051035D	$ 500
Printing		$ 200
Communication		$ 50
		Σ= 16741.6

1.6 Report Content

This chapter presents the general idea of the project and its importance, this chapter also includes the time plan for all over the project.

Chapter two presents Background about water resources and situation in Palestine.

Chapter three presents desalination technology including thermal and membrane processes and other technologies.

Chapter four presents design of membrane desalination technology.

Chapter five presents design and select of photovoltaic Cells and evacuated tube.

Chapter six presents description a desalination system based on combining solar energy with membrane module technology.

Chapter seven presents calculations and selections of the desalination system.

Chapter eight presents recommendations and conclusions.

Chapter Two 2

Background about Water Resources And Situation in Palestine

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Chapter Two

Background about Water Resources and Situation in Palestine

2.1 Introduction

Palestine is experiencing a severe water crisis caused mainly by the lack of control over the Palestinian water resources.

At present the average per capita water consumption by the Palestinian population is approximately 55 liter per cubic per day (l/c/d), or 55% of the World Health Organization (WHO) minimum standard of 100 liter per cubic per day (l/c/d).

The above statements show that the communal water supply for the Palestinian population is substantially inadequate by international standards.

The available water resources in the Middle East are scarce, limited, fragile and threatened. They are already exploited, especially in Palestine.

The water resources in the countries of the sub-region (the Jordan River Basin) are limited in absolute terms; the average per capita availability is extremely low as illustrated in the table below.

A large proportion of the water resources in the Middle East in general, and in Palestine as particular, are Tran's boundary and final arrangements on water resources allocation between Palestinians and "Israelis" are not yet in place for "fair and equitable apportionment".

Average per capita availability in the countries of the Jordan River Basin is about 455m^3, which is low compared with other regions, as for example 3283 m^3 in Asia, 5184 m^3 in Western Europe or 18,742 in North America.

The average per capita availability in Gaza Strip and West Bank, which is 105 m^{3}d, the lowest in the world, all five parties listed above are riparian to the Jordan River catchment which has an average annual total discharge of 1320 Mm^3, with "Israel" abstracting about 645 Mm^3, Jordan abstracting about 485 Mm^3, and Syria abstracting about 200 Mm^3. "Israel" inhibited Palestine from the access to the Jordan River water since its occupation in 1967. The Middle East region's natural water is not only threatened, it is also threatening. [2]

Table 2.1 Per Capita Renewable Availability In the Countries of the Jordan River Basin.

	Annual with drawals (billions of m^3)	Per-capita renewable availability (m^3)
Jordan	1.0	213
Lebanon	0.8	1200
Syria	5.5	385
Palestine(Gaza Strip and West Bank)	0.2	105

"Israel"	1.9	375

2.2 Water Resources

2.2.1 Surface water

Surface water is considered to be of minor importance in the West Bank. There is only one river which the West Bank has access to, that is the Jordan River. There are also four permanent wadis in the area, Wadi Fara'a, Qilt, Malih and Auja. In addition to that, there are some other surface water bodies like the seasonal lakes of Marj Sanur.

2.2.2 Groundwater

Groundwater is the main source of water in Palestine (Gaza Strip and West Bank). The West Bank aquifer system has three major drainage basins:

1. The Western Aquifer System, which is the largest, has a safe yield of 365 MCM per year (of which 40 MCM brackish). Eighty percent of the recharge area of this basin is located within the West Bank boundaries, whereas 80% of the storage area is located within 1967 occupation borders. Groundwater flow is towards the coastal plain in the west, making this a shared basin between "Israelis" and Palestinians.

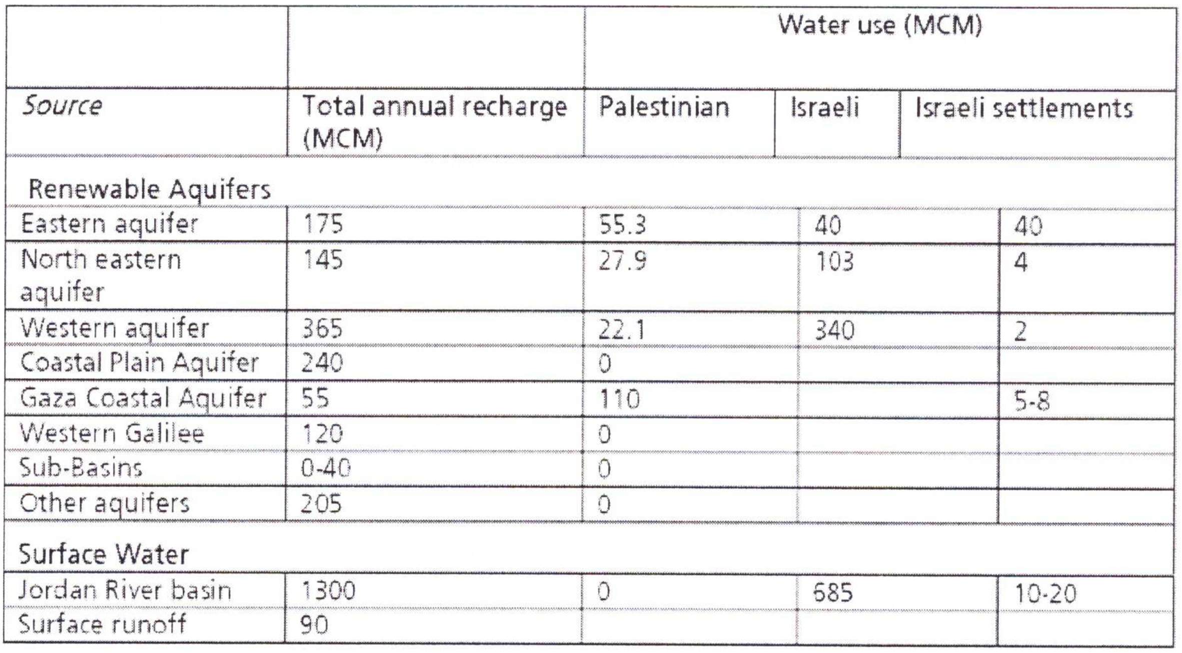
The groundwater being mainly of good quality, this source is largely used for municipal supply.

2. The Northeastern Aquifer System has an annual safe yield of 145 MCM (of which 70 MCM brackish).Palestinians consume only about 18% of the safe yield of their aquifers in the Jenin district and East Nablus (Wadi Al Far'a,Wadi El Bathan, as well as Aqrabaniya and Nassariya) for both irrigation and domestic purposes. There are 86 Palestinian wells in this aquifer system (78 irrigation wells and 8 domestic wells). The general groundwater flow is towards the Bisan natural springs in the north and northeast.

3. The Eastern Aquifer System has a safe yield of 175 MCM per year (of which 70 MCM brackish). It lies entirely within the West Bank territory and was used exclusively by Palestinian villagers and farmers until 1967. After 1967, "Israel" expanded its control over this aquifer and began to tap it, mainly to supply Israeli settlements implanted in the area. The most important springs in the West Bank are in this basin. Seventy-nine springs with an average discharge greater than 0.1 L/s provide 90% of the total annual spring discharge in the West Bank. There are 122 Palestinian groundwater wells in this aquifer system (109 for irrigation and 13 for domestic use).

The main Gaza Costal Aquifer is a continuation of the shallow sandy/sandstone coastal aquifer of “Israel”, About 2200 wells tap this aquifer with depths mostly ranging between 25 and 30 meters. Its annual safe yield is 55 MCM, but the aquifer had been over pumped at the rate of more than 120 MCM annually resulting in a lowering of the groundwater table below sea level and saline water intrusion in many areas. The main sources of salinity are deep saline water intrusion from deeper saline strata, sea water intrusion, and return flows from very intensive irrigation activities in Gaza. [3]

Table 2.2 Available Water Resources in Palestine.



		Water use (MCM)		
Source	Total annual recharge (MCM)	Palestinian	Israeli	Israeli settlements
Renewable Aquifers				
Eastern aquifer	175	55.3	40	40
North eastern aquifer	145	27.9	103	4
Western aquifer	365	22.1	340	2
Coastal Plain Aquifer	240	0		
Gaza Coastal Aquifer	55	110		5-8
Western Galilee	120	0		
Sub-Basins	0-40	0		
Other aquifers	205	0		
Surface Water				
Jordan River basin	1300	0	685	10-20
Surface runoff	90			

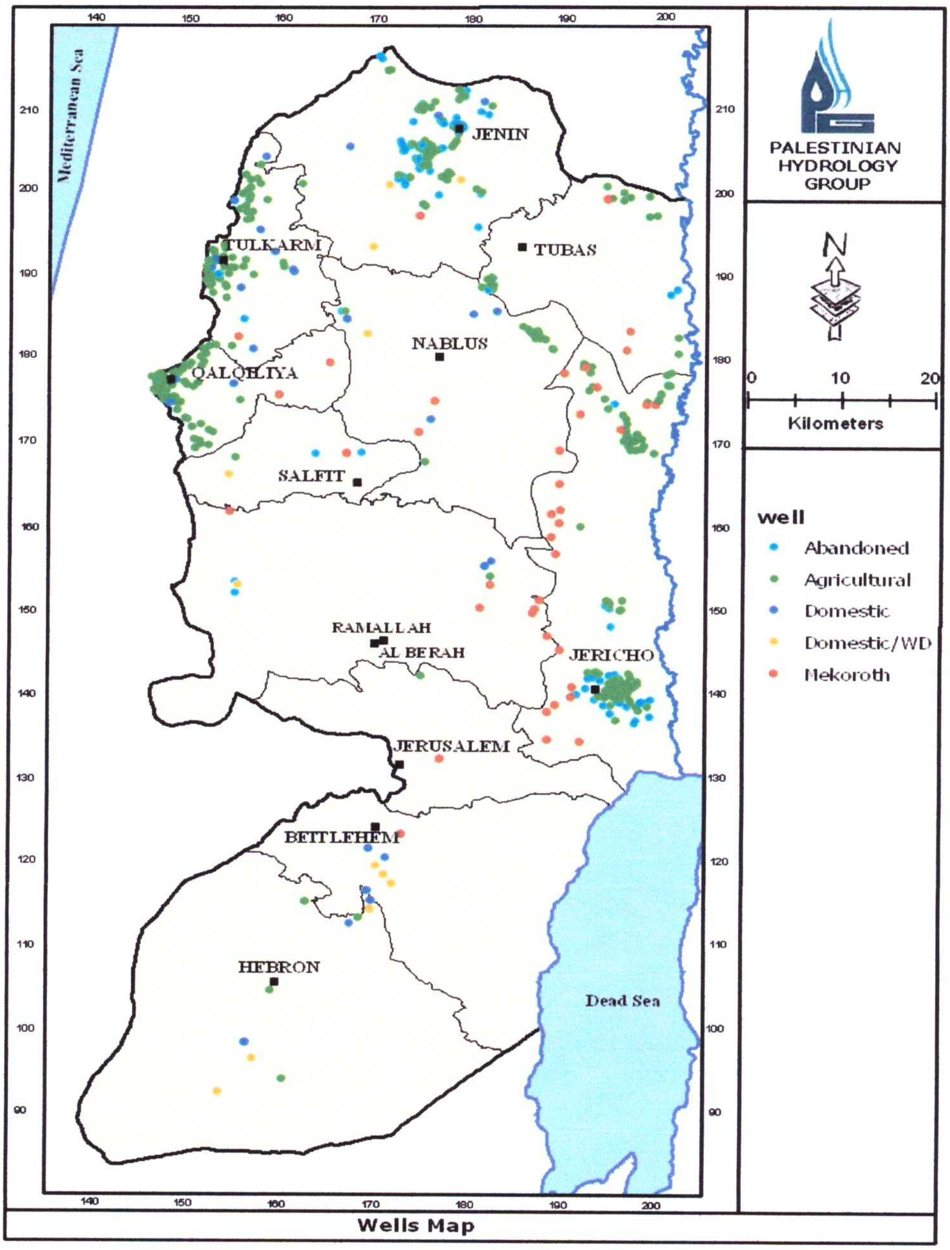


Figure 2.1 The Distribution of Ground Water Wells in West Bank.

2.2.3 Springs

There are 297 springs in the West Bank, 114 out of which are considered to be the main ones with substantial yield quantities. Usually there are fluctuations in the yield of some of these springs in the different years, depending on the rainfall quantities, and thus the recharge to groundwater. However, their average annual yield is estimated to be around 60.8Mm^3/y. Most of the water quantities from springs are used for irrigation, while only around 1.6 Mm^3/y are used for domestic consumption for the time being. Unfortunately, information about the use of each of these springs (domestic or agricultural) is not available, but it is true for many of them that their water is used for the two purposes. [4]

2.2.4 Non-Conventional Water Resources (Cisterns)

Among the other resources, cisterns are of major importance in the West Bank Governorate .They are widely distributed throughout the area, even though the attention paid to them is different from one place to another in the West Bank. The water quantities in the cisterns are used mainly for domestic purposes. The typical form of these cisterns is to collect water from the roofs of the buildings in the winter season and store it in an underground hole in most of the cases. The dimensions of these cisterns are usually different, but mostly have a volume ranging between 60–100 m^3. Cisterns act as a major source of domestic water supply in the localities that do not have water supply networks. It is estimated that 6.6 Mm^3 is utilized from the cisterns. In localities where water networks exist, cisterns still act as another good source of domestic water supply.[5]

2.2.5 Wastewater Reuse

The reuse of wastewater has been thoroughly investigated in many studies performed for the water sector in Palestine (Gaza Strip and West Bank). The main issues concerning the reuse of wastewater such as the collection system, treatment plants, regulations, standards and guidelines are not available.

2.2.6 Brackish Water Desalination

It is a known fact that the Gaza aquifer and some potential sources from the eastern aquifer in the West Bank suffer from a high salinity rate. It is estimated that $53Mm^3/y$ of brackish water in the West Bank from the al-Fashkah springs, and most of the Gaza aquifer, need to be desalinated. [6]

2.3 Water Situation in Palestine

The picture is speaking.

2.3.1 Water Supply Localities With and Without Water Networks

Around 88% residing in 345 localities in the West Bank have piped water supply systems, while 12% of inhabitants residing in 282 localities do not have this service. 55% of the localities in the West Bank have piped water supply systems and 45% are without this service.

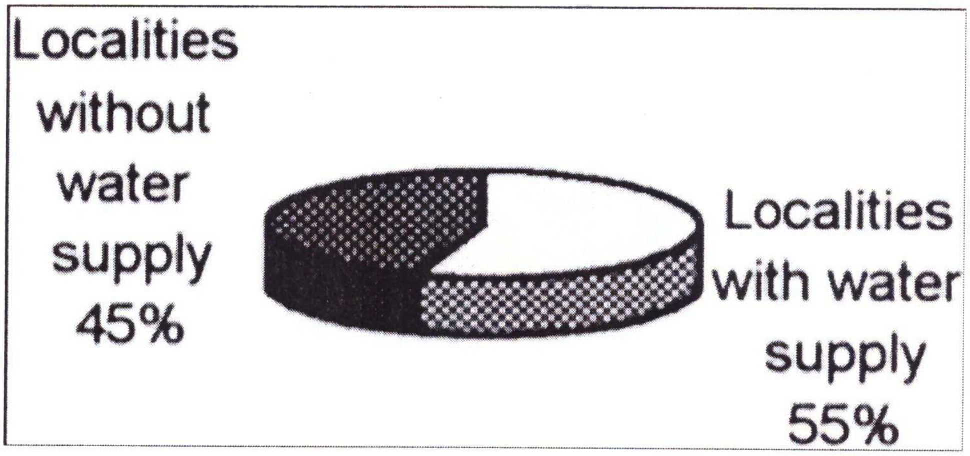


Figure 2.2 Localities With Water Services in West Bank

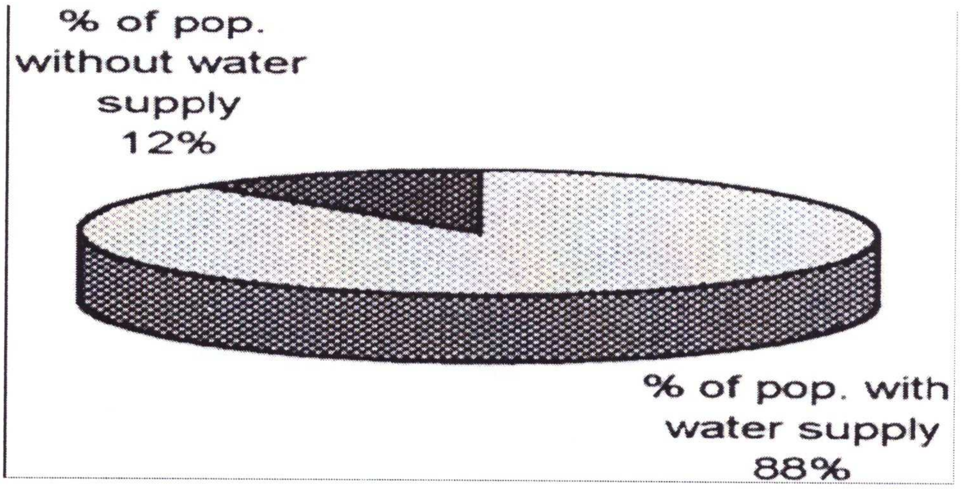


Figure 2.3 Population with Water Services in West Bank

2.3.2 Water Demand

The total water use by the municipal and industrial sectors in Gaza Strip and West Bank during the year 1999 was estimated to be 101Mm^3. An amount of 52Mm^3 was used in the West Bank, whereas a total of approximately 49Mm^3 was used in the Gaza Strip. The water consumed by the agricultural sector is estimated to be 172Mm^3.[7]

The demand projections are estimated based on WHO minimum and average domestic water consumption standards of 100 liter per cubic per day (l/c/d) and 150 (l/c/d). Our estimates distinguish between the consumption of people living in urban areas and people living in rural areas. Based on these target consumption rates and an estimated overall loss rate ranging from 40% to 25% by the year 2020, Table 5 shows the estimated municipal and industrial water demand. A demand of 432Mm^3/y is projected for the year 2020, giving a total. Municipal and industrial annual per capita water consumption of 76m^3/y. According to quoted numbers from "Israeli publications", the total annual municipal and industrial annual per capita water consumption in “Israel” is 150m^3/y, of which around 105m^3/y id for domestic purposes. If the projections of Palestinian demand are based on equal municipal and industrial "Israeli" per capita water consumption, then the total municipal and industrial Palestinian water demand will be 852Mm^3/y for the year 2020.

From different studies and reports, it was estimated that the agriculture water demand for the years 2000, 2005, 2010 and 2020 are about 224 Mm^3, 266 Mm^3, 299 Mm^3 and 353 Mm^3, respectively.[8]

Table 2.3 Municipal and Industrial Water Demand (in Mm^3/y).

	2000	2005	2010	2020
West Bank	141	179	205	262
Gaza	85	109	127	170
Total Palestine	226	288	332	432

2.3.3 The Percentage of Dissolved Substances in Palestine Water

Table 2.4 Limitation of Fresh Water

parameter	unit	Limitation of fresh water	Percentage in Gaza strip ground water	Percentage in West Bank ground water
EC(electrical conductivity)	µS/cm	>2000	11400	4800
TDS(total dissolved solid)	mg/l	>1000	6000	2510
CL(chloride)	mg/l	>250	2500	519

Chapter Three 3

Desalination Technology

Contents:

Chapter Three

Desalination Technology

3.1 Introduction

A desalting device essentially separates saline and brackish water into two streams: one with a low concentration of dissolved salts (the fresh water stream) and the other containing the remaining dissolved salts (the concentrate or brine stream). The device requires energy to operate and can use a number of different technologies for the separation. This section briefly describes the various desalting processes commonly used to desalt saline and brackish water.

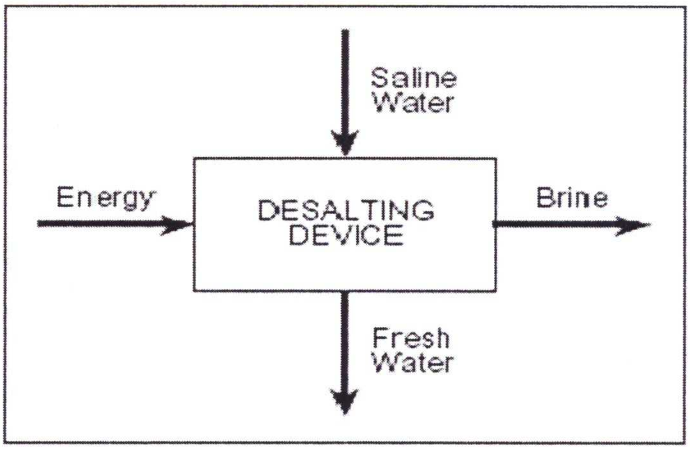


Figure 3.1 Device Process.

3.2 Thermal Processes

About half of the world's desalted water is produced with heat to distill fresh water from sea water. The distillation process mimics the natural water cycle in that salt water is heated, producing water vapor that is in turn condensed to form fresh water. In a laboratory or industrial plant, water is heated to the boiling point to produce the maximum amount of water vapor.

These processes include

3.2.1 Multi-Stage Flash Distillation (MSF)

In the MSF process, seawater is heated in a vessel called the brine heater. This is generally done by condensing steam on a bank of tubes that carry seawater which passes through the vessel. This heated seawater then flows into another vessel, called a stage, where the ambient pressure is lower, causing the water to immediately boil. The sudden introduction of the heated water into the chamber causes it to boil rapidly, almost exploding or flashing into steam. Generally, only a small percentage of this water is converted to steam (water vapor), depending on the pressure maintained in this stage, since boiling will continue only until the water cools (furnishing the heat of vaporization) to the boiling point. [9]

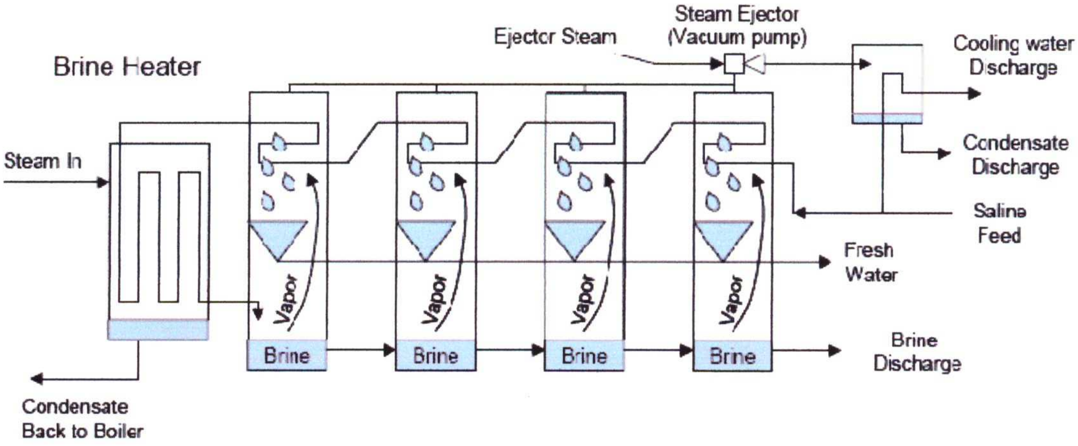


Figure 3.2 Diagram of a Multi-Stage Flash Plant.

3.2.2 Multi-Effect Distillation (MED)

MED, like MSF, takes place in a series of vessels (effects) and uses the principles of condensation and evaporation at reduced ambient pressure in the various effects. This permits the seawater feed to undergo boiling without the need to supply additional heat after the first effect. In general, an effect consists of a vessel, a heat exchanger, and devices for transporting the various fluids between the effects. Diverse designs have been or are being used for the heat exchanger area, such as vertical tubes with falling brine film or rising liquids, horizontal tubes with falling film, or plates with a falling brine film. By far the most common heat exchanger consists of horizontal tubes with a falling film.[10]

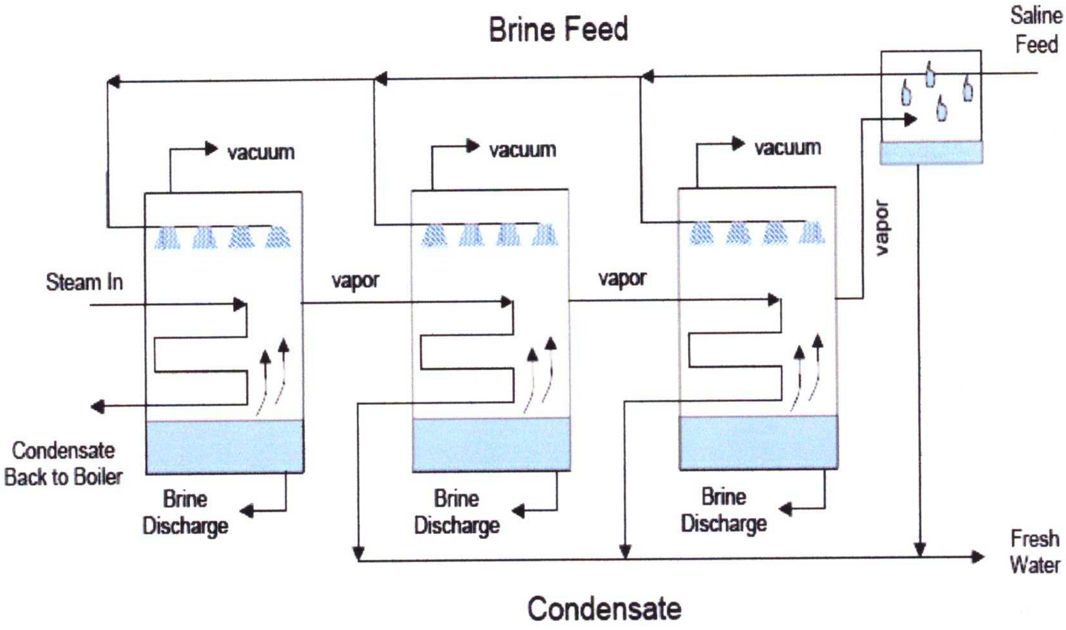


Figure 3.3 Multi-effect distillation.

3.2.3 Vapor Compression (Thermal and Mechanical)

Vapor compression processes rely on reduced pressure operation to drive evaporation. The heat for the evaporation is supplied by the compression of the vapor, either with a mechanical compressor (mechanical vapor compression, MVC), or a steam ejector (thermal vapor compression, TVC). Vapor compression processes are particularly useful for small to medium installations, [MVC units typically range in size up to about 3,000 m^3/day while TVC units may range in size to 20,000 m^3/day. MVC systems generally have only a single stage, while TVC systems have several stages.

This difference arises from the fact that MVC systems have the same specific power consumption (power/unit water produced) regardless of the number of stages, while the thermal efficiency of TVC systems is increased by adding additional stages. Thus the main advantage of adding effects to an MVC system is simply increased capacity. [11]

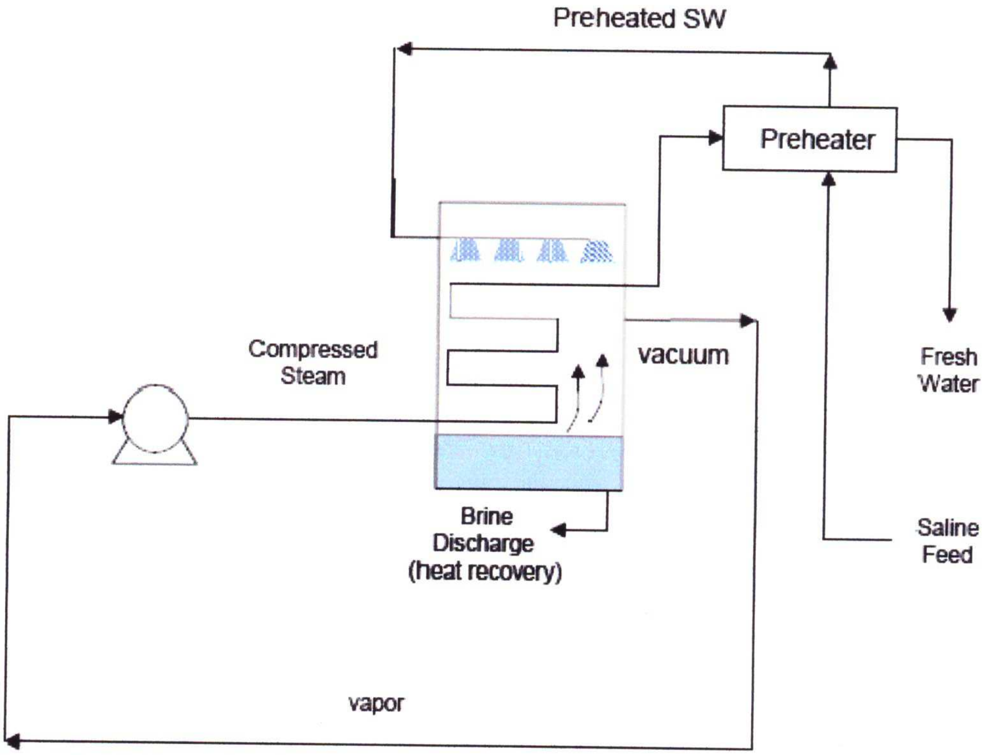


Figure 3.4 Schematic of Single Stage Mechanical Vapor Compression Desalination Process.

3.3 Membrane Processes

Membrane distillation was introduced commercially on a small scale during the 1980s, but it has had demonstrated no commercial success. As the name implies, the process combines both the use of distillation and membranes. In the process, saline water is warmed to enhance vapor production, and this vapor is exposed to a membrane that can pass water vapor but not liquid water. After the vapor passes through the membrane, it is condensed on a cooler surface to produce fresh water. In the liquid form, the fresh water cannot pass back through the membrane, so it is trapped and collected as the output of the plant.

The main advantages of membrane distillation lie in its simplicity and the need for only small temperature differentials to operate. This has resulted in the use of membrane distillation in experimental solar desalting units. However, the temperature differential and the recovery rate, similar to the MSF and MED processes, determine the overall thermal efficiency for the membrane distillation process. Thus, when it is run with low temperature differentials, large amounts of water must be used, which affects its overall energy efficiency.

3.3.1 Reverse Osmosis

Reverse osmosis (RO) is a membrane separation process in which the water from a pressurized saline solution is separated from the solutes (the dissolved material) by flowing through a membrane.

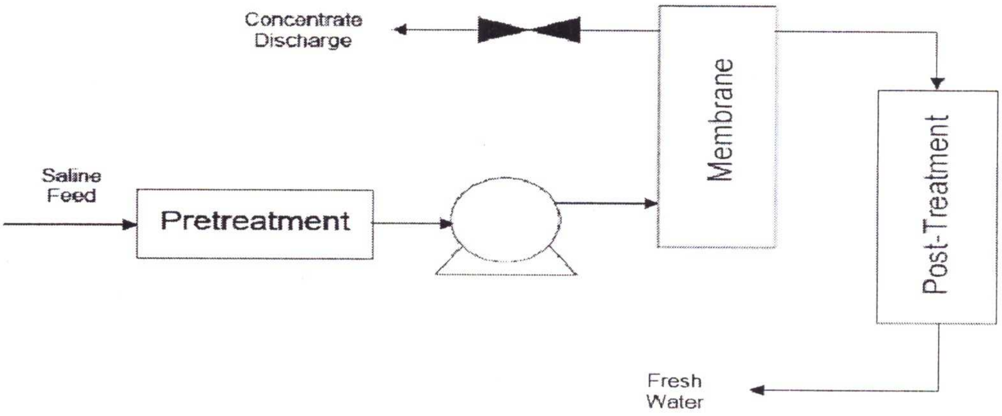


Figure 3.5 Block Diagram of Reverse Osmosis Operations.

Post-Treatment might consist of the removing gases such as hydrogen sulfide and adjusting the pH.

3.3.2 Electrodialysis

Electrodialysis (ED) utilizes a direct current source and a number of flow channels separated by alternating anion and caution selective membranes to achieve the separation of water and dissolved salts. Since the driving force for the separation is an electric field, ED is only capable of removing ionic components from solution, unlike (RO) or distillation. [12]

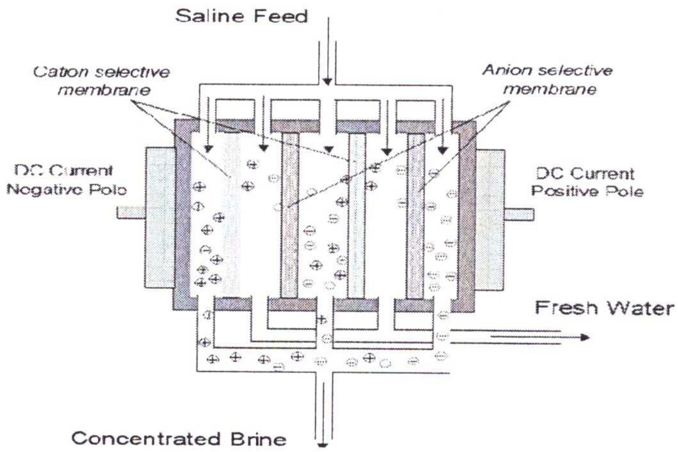


Figure 3.6 Diagram of Electrodialysis Desalination Process.

3.4 Other processes

3.4.1 Humidification Processes

Humidification processes are based on thermally driven evaporation of water; the evaporating water is not processed as pure vapor or steam, but rather is used to humidify a process gas stream (typically air). Then Humidification processes are typically designed to operate at low temperatures, allowing them to make use of low grade or waste heat.

Figure 3.7 Solar Humidification Test Units.

3.4.2 Crystallization Processes

These desalination processes are based on a liquid to solid phase change coupled with a physical process like gas hydrates (or clathrates) to separate the solids from the remaining liquid phase.

The bulk handling of solids is an added complexity that is not required for other processes. The phase change must be selective to either the water or the salt in order for the separation to achieve the desired result. [13]

3.4.3 Freezing

During the process of freezing, dissolved salts are naturally excluded during the initial formation of ice crystals. Cooling saline water to form ice crystals under controlled conditions can desalinate seawater. Before the entire mass of water has been frozen, the mixture is usually washed and rinsed to remove the salts in the remaining water or adhering to the ice crystals, the ice is then melted to produce fresh water. Theoretically, freezing has some advantages over distillation, which was the predominant desalting process at the time the freezing process was developed, these advantages include a lower theoretical energy requirement for single stage operation, a reduced potential for corrosion, and few scaling or precipitation problems, the disadvantage is that it involves handling ice and water mixtures that are mechanically complex to move and process.

3.4.4 Solar and Wind-Driven Desalters

Desalting units that use solar collectors or wind energy devices to provide heat or electrical energy also have been built to operate standard desalting processes like (RO), (ED), or distillation. The economics of operating these plants tend to be related to the cost of producing energy with these alternative energy devices. Cost tends to be high, but is expected to improve as development of these energy devices continues.

3.4.5 Co-generation

Most of the distillation plants installed in the Middle East and North Africa have operated under this principle the electricity is produced with high-pressure steam to run turbines that in turn power electric generators. In a typical case, boilers produce high-pressure steam at about 540C (1,000F). As this steam expands in the turbine, its temperature and energy level is reduced. Distillation plants need steam whose temperature is about 120C (248F) or below, and this can be obtained by extracting the lower temperature steam at the low pressure end of the turbine after much of its energy has been used to generate electricity. This steam is then run through the distillation plant's brine heater, thereby increasing the temperature of the incoming seawater. The condensate from the steam is then returned to the boiler to be reheated for use in the turbine.

The main advantage of a co-generation system is that it can significantly reduce the consumption of fuel; one of the disadvantages is that the units are permanently connected together and, for the desalination plant to operate efficiently, the steam turbine must be operating. This permanent coupling can create a problem with water production, when the demand for electricity is reduced or when the turbine or generator is down for repairs. [14]

Chapter Four 4

Membrane Desalination Technology

Contents:

Chapter four

Membrane Desalination Technology

4.1 Introduction

4.1.1 Objectives

The objective of this chapter is to present elements of membrane Separation processes and to explain principles of membrane separation. The material also defines ranges for application of different membrane processes and summarizes performance parameters of membrane separation processes. In addition, an outline is made for different construction materials and module configurations. This also includes components of the RO desalination process.

4.1.2What is a Membrane

The membrane can be defined essentially as a barrier, which separates two phases and restricts transport of various chemicals in a selective manner.

A membrane is a thin film of porous material that allows water molecules to pass through it, but simultaneously prevents the passage of larger and undesirable molecules such as viruses, bacteria, metals, and salts.

4.1.3 Historical Background

Membranes are an intimate part of being alive. Several examples are simple to cite:

- The skin in all mammals is a very efficient and highly selective type of membrane controlling release of sweat to cool off the bodies through evaporation of tinny water droplets during hot weather. Skin selectivity as apparent, when it's cut the fine blood cells and vessels that runs underneath the skin are broken and releases its blood content. A healthy and intact skin does not release blood.

- The lungs are also a good example of effective membranes, where fine cells within the lungs allow passage of oxygen from the inhaled air and release carbon dioxide into the same stream. The lungs as a membrane prevents permeation of the nitrogen in the inhaled air, irrespective of its high content.

- The kidney membranes regulate the water, salt ions, proteins, and othernutrient within the body. The kidneys are extremely efficient that a healthybody can survive with a quarter of both kidneys.

- On a much smaller scale, membrane walls in single cells within mammals,bacteria, and other microorganisms maintains the cell contents intact and regulate the input/output rates of nutrients or products .

Since the early days of civilization mankind have adopted simple forms of membranes. In early agriculture communities, household sieves were invented and developed to separate fine grain ground from coarse grain particles and shells.Similarly, cheesecloth was made from cotton fibers and used to manufacture cheese. Both forms of separation are based on differences in particle size or molecular size.

However, developments in membrane technology have focused on adoption of other separation mechanisms, such differences in solution and diffusion rates of various species across the membrane material.

Other than the sieve type membrane use of artificial membranes is rather new. Major landmarks in use of artificial membranes are summarized in the following points:

- In 1823, Dutrochet gave correct explanation of osmosis (passage of solvent across a membrane from low to high concentration) and dialysis (passage of solute across a membrane from high to low concentration).

- In 1867, Traube and Pfeffer performed one of the first quantitative studies on performance of artificial membranes.

- Moritz Taube, 1867, prepared the first synthetic membrane.

- In the late 1800's Graham discovered that arranging a membrane between areservoir of pressurized air and another reservoir of unpressurized air could produce oxygen-enriched air.

- Early use of membranes was applied to recovery of NaOH by dialysis from wastewater containing hemicellulose from the viscose-rayon industry.

- Also, uranium isotopes (235 and 238) are separated in the vapor phase through porous membranes.[15]

4.2 Types Of Membranes

A membrane can be homogenous or heterogeneous, symmetric or asymmetric in structure, solid or liquid can carry a positive or negative charge or be neutral or bipolar. Transport through a membrane can be effected by convection or by diffusion of individual molecules, induced by an electric field or concentration, pressure or temperature gradient. The membrane thickness may vary from as small as 100 micron to several mms.[16]

4.2.1 Microporous Membranes

The membrane behaves almost like a fibre filter and separates by a sieving mechanism determined by the pore diameter and particle size. Materials such as ceramics, graphite, metal oxides, polymers etc. are used in making such membranes. The pores in the membrane may vary between 1 nm-20 microns.

4.2.2 Homogeneous Membranes

This is a dense film through which a mixture of molecules is transported by pressure, concentration or electrical potential gradient. Using these membranes, chemical species of similar size and diffusivity can be separated efficiently when their concentrations differ significantly.

4.2.3 Asymmetric Membranes

An asymmetric membrane comprises a very thin (0.1-1.0 micron) skin layer on a highly porous (100-200 microns) thick substructure. The thin skin acts as the selective membrane. Its separation characteristics are determined by the nature of membrane material or pore size, and the mass transport rate is determined mainly by the skin thickness. Porous sub-layer acts as a support for the thin, fragile skin and has little effect on the separation characteristics.

4.2.4 Electrically Charged Membranes

These are necessarily ion-exchange membranes consisting of highly swollen gels carrying fixed positive or negative charges. These are mainly used in the electrodialysis.

4.2.5 Liquid Membranes

A liquid membrane utilizes a carrier to selectively transport components such as metal ions at relatively high rate across the membrane interface.

4.3 Elements of Membrane Separation

A number of membrane-based desalination processes are used on industrial scale. As is shown in Fig.4.1, the membrane-based processes include reverse osmosis, nanofiltration, ultrafiltration, and microfiltration.

Differences among these processes are shown in Fig.4.1.

Where:

- Microfiltration operates on a particle size range of 0.15 μm to 0.15μm.
- Ultrafiltration operates on a particle size range of 0.15 μm to $5x10^{-2}$ μm.
- Nanofiltration operates on a particle size range of $5x10^{-2}$μm to $5x10^{-3}$ μm.
- Reverse osmosis operates on a particle size range of $5x10^{-3}$ μm to 10^{-4} μm.

There is an inherent difference in the separation mechanism in all filtration processes and the reverse osmosis process. In filtration, separation is made by a sieving mechanism, where the membrane passes smaller particles and retains larger ones. In osmosis or reverse osmosis processes the membrane permeates only the solvent and retains the solute. Further distinction of the four membrane processes is shown in Fig.4.1. As is shown, the microfiltration, ultrafiltration, and nanofiltration processes are used to separate the suspended material. On the other hand, the reverse osmosis process is used to separate dissolved solids. Nanofiltration is used for partial softening of brackish water.

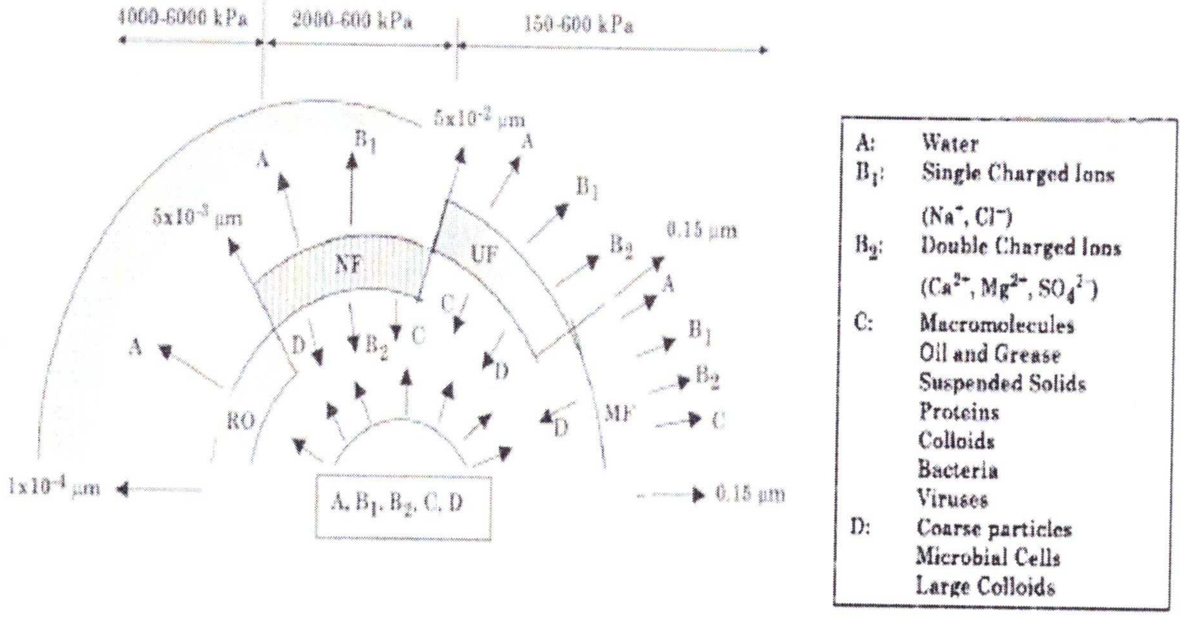


Figure 4.1 Membrane Separation Processes and Corresponding Particle Sizes.

4.3.1 Reverse Osmosis

Reverse osmosis (RO) is the most widely used process for seawater desalination. RO process involves the forced passage of water through a membrane against the natural osmotic pressure to accomplish separation of water and ions.

Reverse Osmosis (RO) is a physical process that uses the osmosis phenomenon, i.e., the osmotic pressure difference between the saltwater and the pure water to remove salts from water (Figure4.1).In this process, a pressure greater than the osmotic pressure is applied on saltwater (feed water) to reverse the flow, which results in pure water (freshwater) passing through the synthetic membrane pores separated from the salt. A schematic for the osmosis and reverse osmosis phenomenon are shown in Fig.4.1. In this configuration, the direction of solvent flow is determined by its chemical potential, which is a function of pressure, temperature and concentration of dissolved solids. Pure water in contact with both sides of an ideal semi-permeable membrane at equal pressure and temperature has no net flow across the membrane because the chemical potential is equal on both sides. If a soluble salt is added on one side, the chemical potential of this salt solution is reduced. Osmotic flow from the pure water side across the membrane to the salt solution side will occur until the equilibrium of chemical potential is restored.

Equilibrium occurs when the hydrostatic pressure differential resulting from the volume changes on both sides is equal to the osmotic pressure. This is a solution property independent of the membrane. Application of an external pressure to the salt solution side equal to the osmotic pressure will also cause equilibrium. Additional pressure will raise the chemical potential of the water in the salt solution and cause a solvent flow to the pure water side, because it now has alower chemical potential.

The RO process is effective for removing total dissolved solids (TDS) concentrations of up to 45,000 mg/L, which can be applied to desalinate both brackish water and seawater.

Reverse osmosis needs energy to operate the pumps that raise the pressure applied to feed water. The amount of pressure required directly relates to the TDS concentration of the feed water. For brackish water, the pump pressure requirement is between 140 and 400 psi. For seawater, pumps may need to generate up to 1200 psi. Therefore, the TDS concentration of the feed water has a substantial effect on the energy use and the cost of the product water.[17]

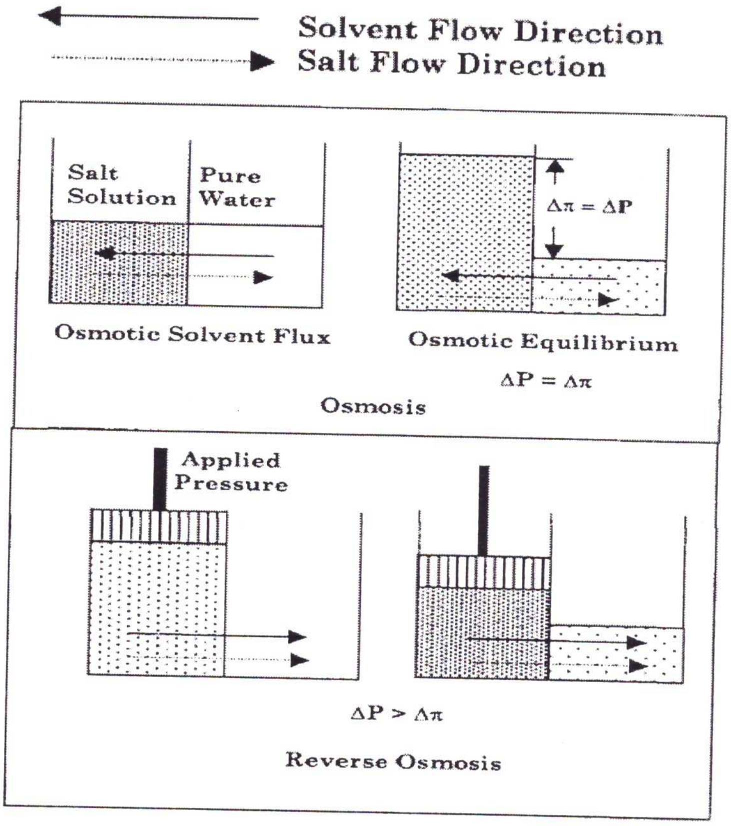


Figure 4.2 Osmosis and Reverse Osmosis Processes.

4.4 Performance Parameters

The RO process is defined in terms of a number of variables, which includes:

- Permeate recovery
- Osmotic and operating pressure
- Salt rejection

Membrane manufacturing companies define system specifications in terms of the feed quality, which includes salinity and temperature.

4.4.1 Permeate Recovery

Permeate recovery is another important parameter in the design and operation of RO systems. Recovery or conversion ratio of feed water to product (permeate) is defined by:

$$R_p = (Q_p/Q_f)*100\% \qquad (4.1)$$

Where:

R_p: is Permeate recovery ratio (in %).

Q_p: is the permeate water flow rate.

Q_f: is the feed water flow rate.

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. Also, a higher salt concentration in the feed-brine solution increases the osmotic pressure, reducing the (ΔP-Δπ) and consequently reducing the product water flow rate.

Where:

ΔP: is the hydraulic pressure differential across the membrane, kPa.

Δπ :is the osmotic pressure difference across the membrane, kpa.

4.4.2 Osmotic and Operating Pressure

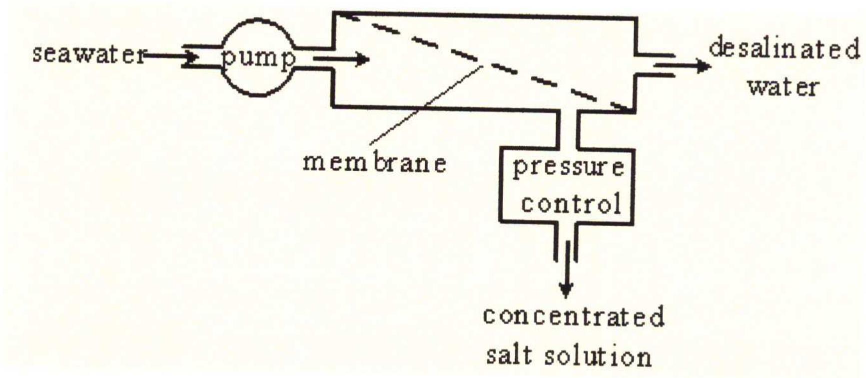


Figure 4.3 Basic Scheme of Desalination by Reverse Osmosis

Seawater desalination requires minimal energy consumption equal to the osmotic pressure times the volume of desalinated water [18] , the osmotic pressure is nearly proportional to the salt concentration in the water.

The osmotic pressure, π, of a solution can be determined experimentally by measuring the concentration of dissolved salts in the solution. The osmotic pressure is obtained from the following equation (Van‘t Hoff equation)

$$\pi = RT\,\Sigma X_i \tag{4.2}$$

where:

π: is the osmotic pressure (kPa).

T: is the temperature (K).

R: is the universal gas constant, 8.314 kPa m^3/kgmol K

ΣX_i: is the concentration of all constituents in a solution (kgmol/m^3).

An approximation for π may be made by assuming that 1000 ppm of Total Dissolved Solids (TDS) equals to 75.84 kPa of osmotic pressure. [19]

Operating pressure is adjusted to overcome the adverse effects of the following:

- Osmotic pressure
- Friction losses
- Membrane resistance
- Permeate pressure

If the operating pressure is set equal to the sum of the above resistances the net permeate flow rate across the membrane would be minimal or equal to zero; therefore, the operating pressure is set at higher value in order to maintain economical permeate flow rate.

The pump pressure must be higher than the osmotic pressure in order to force seawater flow through the membrane and permeate water out of the module. The flow rate is proportional to the difference between the two pressures. When they are equal water does not flow through the membrane, and if the pump pressure is lower than the osmotic pressure, permeate water will flow back towards the concentrated salt water.

Consider an example where the water Permeate Recovery is 0.5. That is, for every two volumes of seawater pumped into the module one volume will come out as permeate water and one as doubly concentrated salt water. The high-pressure pump consumes energy equal to the pump pressure times the volume of water that it pumps. Since the pump has to pump two V volumes of seawater in order to produce one V volume of permeate water, the consumed work (w) is:

$$W = P_{pump} (2 \cdot V) \tag{4.3}$$

Since the osmotic pressure of the concentrated salt water is twice as much as that of seawater, $P_s = 2 \cdot P_{sea}$, the required pump pressure will be:

$$P = 2 \cdot P_{sea} + \Delta P \tag{4.4}$$

ΔP is the overpressure, above the osmotic pressure, that drives water flow through the membrane. The work then becomes:

$$W = (4 \cdot P_{sea} + 2\Delta P) \cdot V \tag{4.5}$$

It is, therefore, more than four times higher than the minimal theoretical desalination energy ($P_{sea} \cdot V$).

In summary, the practical desalination energy is higher than the theoretical minimum for two reasons:

a. The feed volume of seawater is higher than the volume of permeate-water.
b. The osmotic pressure of concentrated salt water within desalination module is higher than that of seawater.

The work consumed by the pump is equal to P·V where P is the pump pressure and V is the volume of seawater that it pumps. All this work is transformed into heat.

P_s is the osmotic pressure of the concentrated salt solution within a membrane module and ΔP is the over pressure that drives water flow through the membrane. The pump pressure P is equal to their sum, $P = P_s + \Delta P$

V_{permeate} is the volume of desalinated water produced by the process and $V_{\text{concentrate}}$ is the volume of concentrated salt solution that returns to the sea. In systems that do not apply energy recovery devices the overall pumped volume is equal to the sum $V = V_{\text{permeate}} + V_{\text{concentrate}}$. In systems that apply energy recovery devices of 100% efficiency the volume pumped by the pump is equal to the volume of desalinated water, $V = V_{\text{permeate}}$.

4.4.3 Salt Rejection

Salt rejection is defined by:

$$SR = 100\% \left(1 - (Xp/Xf)\right) \qquad (4.6)$$

And this equation provide from the mass balance approach.

Where:

SR: is the salt rejection.

X_f: is the feed salinity, kg/m^3.

X_p: is the permeate salinity, kg/m^3

For example, a feed seawater with 42,000 ppm and a permeate with a salinity of 150 ppm gives a percentage salt passage of 99.64%. Similarly, for a brackish water feed with salinity of 5000 ppm and a permeate salinity of 150 ppm gives a percentage salt passage of 97%. The two cases indicate the dramatic difference between the seawater and brackish water desalination membranes. Current membrane technology provides salt rejection values above 99% for both seawater and brackish water membranes.

4.5 RO Membranes

Features of the RO membranes include the following:

- The membranes are formed of thin film of polymeric material several thousand Angstroms thick cast on polymeric porous material. Commercial membranes have high water permeability and a high degree of semi-permeability; that is, the rate of water transport must be much higher than the rate of transport of dissolved ions.
- The membrane must be stable over a wide range of Ph and temperature, and have good mechanical integrity.

- The life of commercial membranes varies between 3-5 years. On average annual membrane replacement rates stand at 5-15%; this depends on the feed water quality, pretreatment conditions, and stability of operation. Major types of commercial reverse osmosis membranes include cellulose acetate (CA) and polyamide (PA).
- It should be noted that membrane choice is often governed by compatibility considerations rather than separation performance and flux related characteristics.

4.5.1 Cellulose Acetate Membranes

The original CA membrane, developed in the late 1950's by Loeb and Sourirajan, was made from cellulose diacetate polymer. Current CA membrane is usually made from a blend of cellulose diacetate and triacetate. The membrane preparation process includes thin film casting, cod bath leaching, and high temperature annealing. The casting process is associated with partial removal of the solvent material by evaporation. The cold bath process removes the remaining solvent and other leachable compounds. The annealing process is made in a hot water bath at a temperature of 60-90°C. The annealing step improves the semipermeability of the membrane with a decrease of water transport and a significant decrease of salt passage.

The CA membranes have an asymmetric structure with a dense surface layer of about 1000-2000 A (0.1-0.2 micron) which is responsible for the salt rejection property. The rest of the membrane film is spongy and porous and has high water permeability. Salt rejection and water flux of a cellulose acetate membrane can be controlled by variations in temperature and duration of the annealing step.

4.5.2 Composite Polyamide Membranes

The composite polyamide membranes are formed of two layers, the first is a porous polysulfone support and the second is a semi-permeable layer of amine and carboxylic acid chloride functional groups. This manufacturing procedure enables independent optimization of the distinct properties of the membrane support and salt rejecting skin. The resulting composite membrane is characterized by higher specific water flux and lower salt passage than cellulose acetate membranes.

Polyamide composite membranes are stable over a wider pH range than CA membranes. However, polyamide membranes are susceptible to oxidative degradation by free chlorine, while cellulose acetate membranes can tolerate limited levels of exposure to free chlorine. Compared to a polyamide membrane,[20]

The surface of cellulose acetate membrane is smooth and has little surface charge. Because of the neutral surface and tolerance to free chlorine, cellulose acetate membranes will usually have a more stable performance than polyamide membranes in applications where the feed water has a high fouling potential, such as with municipal effluent and surface water supplies.

4.6 Membrane Modules

The two major membrane module configurations used for reverse osmosis applications are hollow fiber and spiral wound. Other configurations, which include tubular and plate and frame, are used in the food and dairy industry. [21]

4.6.1 Hollow Fine Fiber

This configuration uses membrane in the form of hollow fibers, which have been extruded from cellulosic or non-cellulosic materials. The fiber is asymmetric in structure and is as fine as a human hair. Millions of these fibers are formed into a bundle and folded in half to a length of approximately 120 cm. A perforated plastic tube, serving as a feed water distributor is inserted in the center and extends the full length of the bundle. The bundle is wrapped and both ends are epoxy sealed to form a sheet-like permeate tube end and a terminal end which prevents the feed stream from bypassing to the brine outlet.

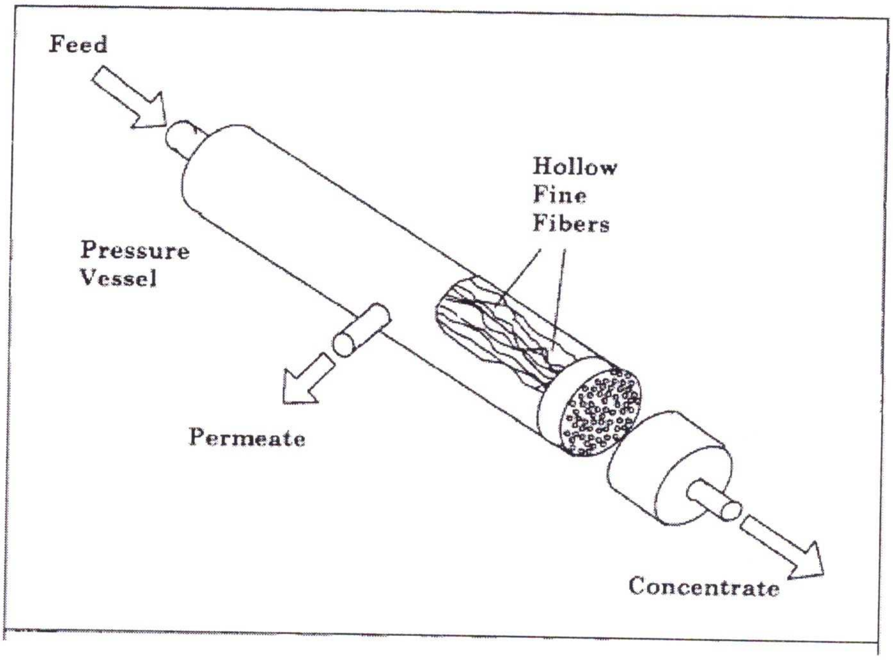
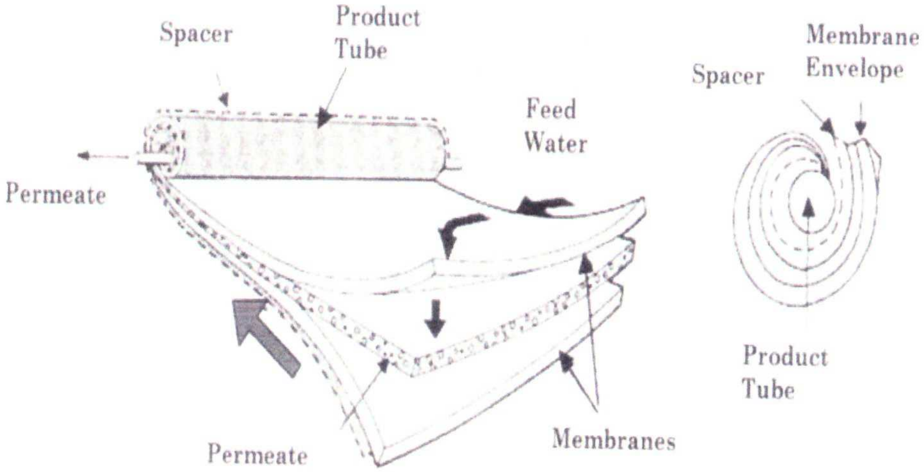


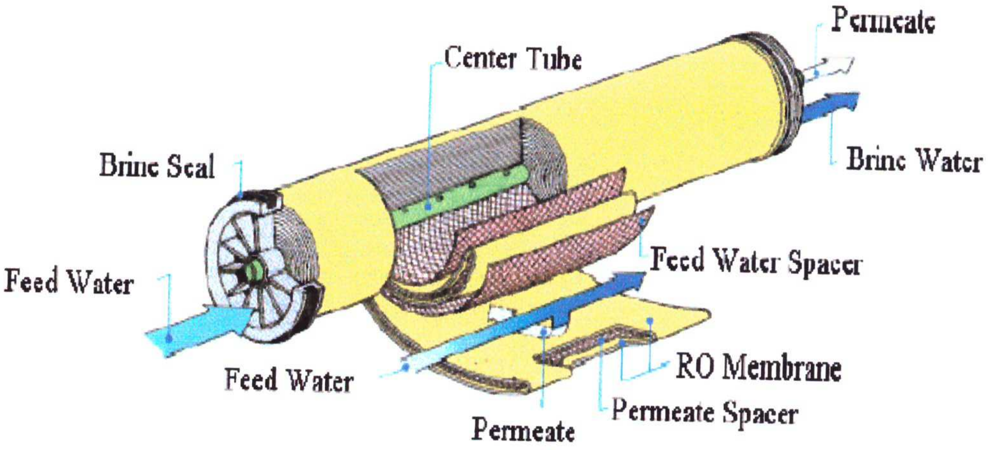
Figure 4.4 Hollow Fiber Membrane Modules.

4.6.2 Spiral Wound

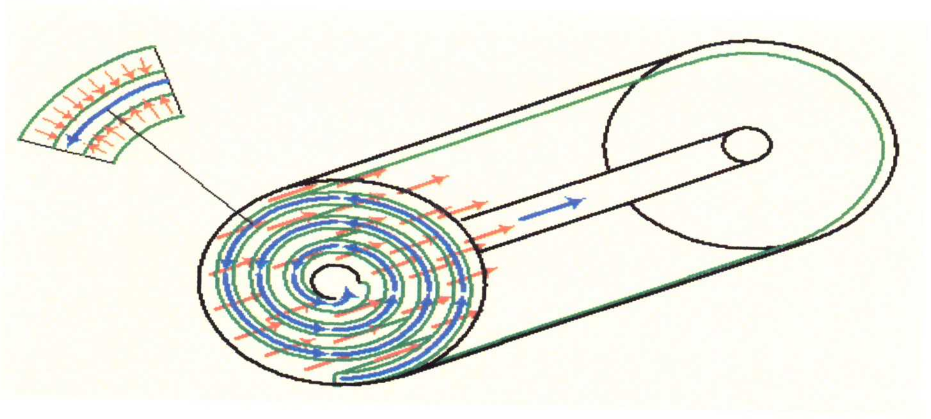
In spiral wound configuration (Fig 4.6), two flat sheets of membrane and separated with a permeate collector channel material to form a leaf. This assembly is sealed on three sides with the fourth side left open for permeate to exit. A feed/brine spacer material sheet is added to the leaf assembly. A number of these assemblies or leaves are wound around a central plastic permeate tube. This tube is perforated to collect the permeate from the multiple leaf assemblies. The feed/brine flow through the element is straight axial path from the feed end to the opposite brine end, running parallel to the membrane surface.[22]


Spacer
Product Tube
Membrane Envelope
Spacer
Feed Water
Permeate
Product Tube
Permeate
Membranes

(a)


Permeate
Center Tube
Brine Seal
Brine Water
Feed Water Spacer
Feed Water
RO Membrane
Feed Water
Permeate Spacer
Permeate

(b)



(c)

Figure 4.5 (a),(b),(c) Spiral Wound Membrane Modules.

4.7 RO Model and System Variables

The RO process is defined in terms of a number of variables, which includes:

- Osmotic pressure
- Water transport
- Salt transport
- Salt passage
- Salt rejection
- Permeate recovery
- Concentration polarization

The following sections include the equations and terms forming the RO simple model. The model is based on the following assumptions:

- Steady state and isothermal operation.
- Permeability coefficients of various salt ions or water are independent of temperature and concentration.
- Similar permeability coefficient for various salt ions.
- The salt flow rate across the membrane is negligible in comparison with the water permeate flow rate.
- Complete mixing within the permeate compartment.
- Salt concentration within the feed compartment varies linearly along the membrane area.

4.7.1 Permeator Mass and Salt Balances

The permeator mass and salt balances are given by the following relations:

$$Qf = Qp + Qb \tag{4.7}$$

$$X_f Q_f = X_p Q_p + X_b Q_b \tag{4.8}$$

Where:

Q_f : is the feed flow rate, kg/s.

Q_p : is the permeate flow rate, kg/s.

Q_b : is the brine flow rate, kg/s.

X_b: is the brine salinity, kg/m^3.

4.7.2Water Transport

The following relation defines the rate of water passage through a semi permeable membrane

$$Q_p = (\Delta p - \Delta \pi)\, K_W.A \tag{4.9}$$

Where:

Q_p: The volumetric rate of water flow through the membrane, m^3/s.

ΔP: The hydraulic pressure differential across the membrane, kPa.

$\Delta \pi$: The osmotic pressure difference across the membrane, kpa.

K_w : The water permeability coefficient, m^3/m^2. s kPa

$$\Delta P = P_a - P_p \tag{4.10}$$

$$\Delta \pi = \pi_a - \pi_p \tag{4.11}$$

Where:

P_p :The permeate hydraulic pressure.

π_p : The permeate osmotic pressure.

P_a: The average hydraulic pressure on the feed side.

π_a: The average osmotic pressure on the feed side.

$$P_a = 0.5\,(p_f + p_b) \tag{4.12}$$

$$\pi_a = 0.5\,(\pi_f + \pi_b) \tag{4.13}$$

Where:

p_f : The hydraulic pressure of the feed stream.

π_f : The osmotic pressure of the feed stream.

p_b: The hydraulic pressure of the reject stream.

π_b :The osmotic pressure of the reject stream.

4.7.3 Salt Transport

The rate of salt flow through the membrane is defined by:

$$Q_s = (X_a - X_p)\, K_s \,.A \tag{4.14}$$

Where:

Q_s : The flow rate of salt through the membrane, kg/s.

K_s : The membrane permeability coefficient for salt, m^3/m^2 s.

X_p : The permeate total dissolved solids concentration, kg/m^3.

A :The membrane area, m^2.

In Eq. (4.14) the term X_a is defined by:

$$X_a = (Q_f X_f + Q_b X_b)/(Q_f + Q_b) \tag{4.15}$$

Where:

X_f : Is the feed salt concentration.

X_b : Is the reject salt concentration.

Equations 4.9 and 4.14 show that for a given membrane:

1. Rate of water flow through a membrane is proportional to net driving pressure differential ($\Delta P - \Delta\pi$) across the membrane.
2. Rate of salt flow is proportional to the concentration differential across the membrane (X_a-X_p) and is independent of applied pressure.

4.7.4 Concentration Polarization

As water flows through the membrane and the membrane rejects salts, 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 effect of concentration polarization is to reduce actual product water flow rate and salt rejection versus theoretical estimates. The effects of concentration polarization are as follows:

- Greater osmotic pressure at the membrane surface than in the bulk feed solution, $\Delta\pi$, and reduced Net driving pressure differential across the membrane (ΔP -$\Delta\pi$).
- Reduced water flow across membrane (M_p).
- Increased salt flow across membrane (M_s).
- Increased probability of exceeding solubility of sparingly soluble salts at the membrane surface, and the distinct possibility of precipitation causing membrane scaling.

The Concentration Polarization Factor (CPF) can be defined as a ratio of salt concentration at the membrane surface (C_s) to bulk concentration (C_b), where:

$$CPF = C_s/C_b \qquad (4.16)$$

An increase in permeate flux will increase the delivery rate of ions to the membrane surface and increase C_s. An increase of feed flow increases turbulence and reduces the thickness of the high concentration layer near the membrane surface. Therefore, the CPF is directly proportional to permeate flow (Q_p), and inversely proportional to average feed flow (Q_f)

Where

$$CPF = K3 \exp(Q_p/Q_f) \qquad (4.16)$$

Where

K3 is a proportionality constant depending on system geometry.

Using the arithmetic average of feed and concentrate flow as average feed flow, the CPF can be expressed as a function of the permeate recovery rate a of membrane element (R_1):

$$CPF = K3 \exp(2R_1/(2-R_1)) \qquad (4.17)$$

The value of the Concentration Polarization Factor of 1.2, corresponds to 18% permeate recovery.

Chapter Five 5

Solar Energy in Desalination

Contents:

Chapter Five

Solar Energy

5.1 Introduction

The sun has produced energy for billions of years. Solar energy is the sun's rays (solar radiation) that reach the earth. Solar energy can be converted into other forms of energy, such as heat and electricity.

Solar energy can be converted to thermal (or heat) energy and used to:

Heat water – for use in homes, buildings, or swimming pools, desalination system.

Heat spaces – inside greenhouses, homes, and other buildings.

Solar energy can be converted to electricity in two ways:

- Photovoltaic (PV devices) or "solar cells" – change sunlight directly into electricity. PV systems are often used in remote locations that are not connected to the electric grid. They are also used to power watches, calculators, and lighted road signs.
- Solar Power Plants – indirectly generate electricity when the heat from solar thermal collectors is used to heat a fluid which produces steam that is used to power generator.

Solar water heating systems classified into two types according to the using of pumps:

1: Active: uses electric pumps to circulate heat absorbing fluid.
2: Passive: depends on natural convection to circulate hot water and heat transfer fluid.

Types of circulation:

1: Direct: hot water from the collectors flow directly.
2: Indirect: the hot water is separated from heat transfer fluid so heat exchanger is needed.

Solar collectors can be either nonconcentrating or concentrating.

Nonconcentrating collectors have a collector area (the area that intercepts the solar radiation) that is the same as the absorber area (the area absorbing the radiation). Flat-plate collectors are the most common. Concentrating collectors, where the area intercepting the solar radiation is greater, sometimes hundreds of times greater than the absorber area.

Five types of solar water heating systems are used to service hot water; thermosphon, drain down, glycol antifreeze, batch-type, and drain back system.

The direct thermosphon system is the simplest and the most widely system that uses in Palestine.

The solar energy is the most common method for water heating in Palestine, about 70% of houses and business use the solar water heating system. [23].

5.1.1 Solar Radiation

Solar energy and the application of solar energy is increasing because the solar radiation is parental source of energy and it is easy to get and collect and it has variety of application. This energy reaches the earth on the form of radiation.

Solar radiation is renewable energy that comes from the sun as a result of a nuclear fusion that takes place in the sun.

The radiation reaches to the earth on the shape of waves, about half of these waves are invisible (short-waves) these waves have a electromagnetic energy .The temperature of solar radiation reaches to 5800K.

5.1.2 Solar Radiation Data

The availability of solar energy is not the same in the word .There are some places in the word which is more suitable for solar energy and benefit from the solar radiation .The location and the altitude affects the amount of received solar radiation.

The following information about radiation data is important to be understood:

1. Whether they are instantaneous measurement or integrated over some period of time.
2. The time or time period of the measurement.
3. Whether the measurement are of beam, diffuse or total radiation and the instrument used.
4. The receiving surface orientation.

West Bank and Gaza strip can be classified into three zones according to the climate in each zone. The coastal areas including Gaza strip, Tulkarem and Qalqiliah, are hot and humid during summer and mild winter. Hilly areas including, from south and north, Hebron, Bethlehem, Jerusalem, Ramallah, Nablus, and Jenin have mild summer and cold winter conditions. The Jordan valley zone including Jericho and the Dead Sea has considerably hot conditions. The following chart shows the monthly solar radiation for Jericho representing the Jordan valley zone.

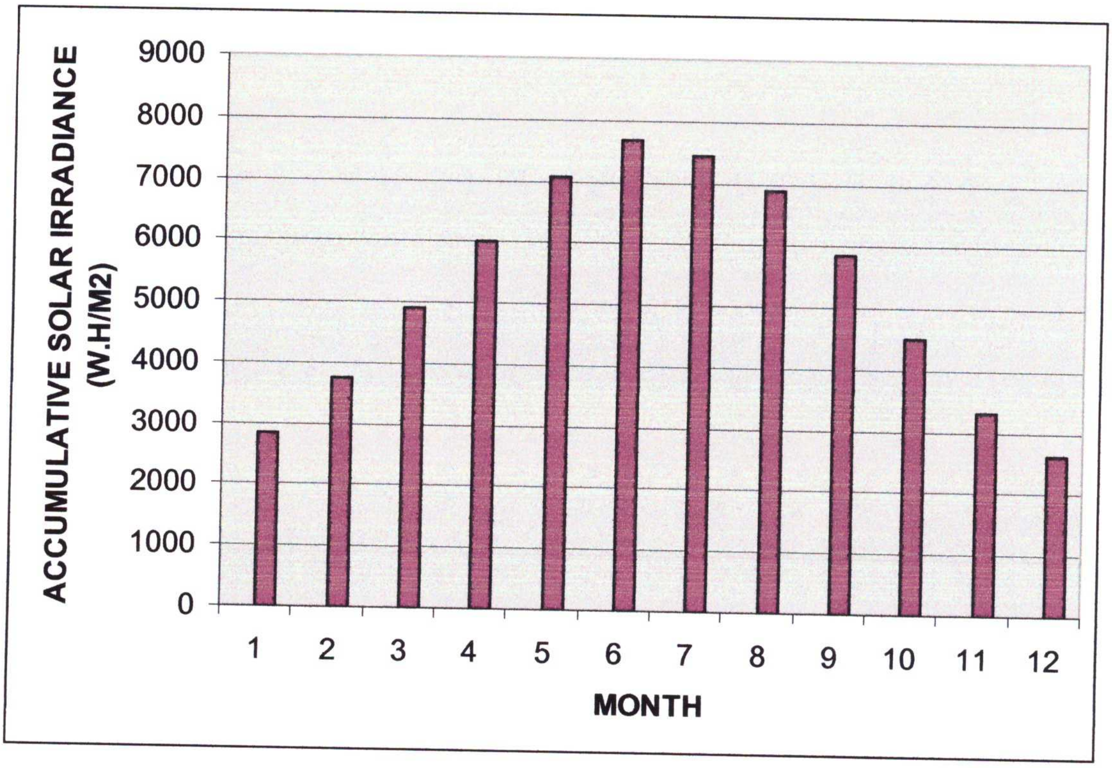


Figure 5.1 Monthly Solar Radiation for Jericho Regions.

The annual mean of solar isolation in Palestine ranges from 5.3-5.7 KWhr\m2 day and the average daylight exceeds 10 hours

5.2 Design of Thermal Energy Conversion System (Evacuated Tube).

5.2.1 Solar Collector

A solar collector is a kind of heat exchanger than transform the solar radiant energy into heat. In the solar collector, the energy transfer is from distant source of radiation energy to fluid. And they are divided into three types.

a. Flat plate collector.
b. Concentrating collectors.
c. Evacuated tube collectors.

Evacuated tube collectors which will be used in this project, because the evacuated tube has a high efficiency and gives a desired temperature at relatively low radiation rate

5.2.1.1 Flat Plate Collector

A flat-plate solar collector is one of three main types of solar collectors, which are key components of active heating solar system.

Flat-plate collectors are the most common solar collectors for use in solar water-heating systems in homes and in solar space heating. A flat-plate collector consists basically of an insulated metal box with a glass or plastic cover (the glazing) and a dark-colored absorber plate. Solar radiation is absorbed by the absorber plate and transferred to a fluid that circulates through the collector in tubes. In an air- based collector the circulating fluid is air, whereas in a liquid-based collector it is usually water.

Flat-plate collectors heat the circulating fluid to a temperature considerably less than that of the boiling point of water and are best suited to applications where the demand temperature is 30-70°C (86-158°F) and/or for applications that require heat during the winter months.

Flat collectors can be mounted in a variety of ways, depending on the type of building, application, and size of collector. Options include mounting on a roof, in the roof it self, or free standing.

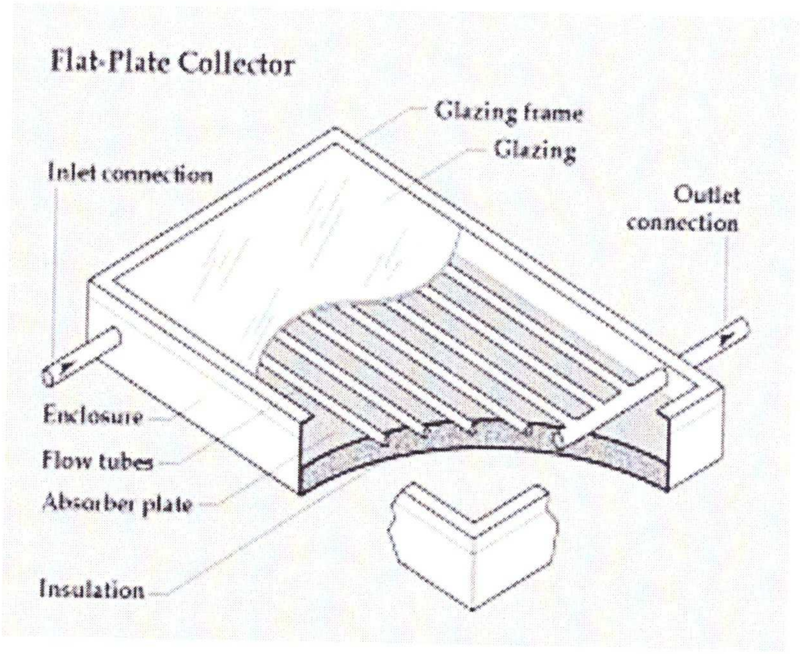


Figure 5.2 Flat-Plate Solar Collector.

5.2.1.2Concentrating Types

1- Parabolic Through Concentrators (PTC)

PTC consists of parabolic reflector and absorber placed at the focal point of the parabolic.

Normally it is installed east-west aligned with one degree of freedom for tracing about axis.

2- Spherical Concentrators

Spherical aberration is seen to be present and causes the reflect flux to be "along a line".

Another way of tracking is to move the absorber rather than the reflecting hemisphere, in this case it is known as station reflector tracking.

3- Compound Parabolic Concentrators (CPC)

CPC is a non-tracking collector; it contains two sections of a parabolic located symmetrically about the collector mid-plane.

4- Central Receiver Collector

Central receiver collector consists of a large field of mirrors on the ground that tracks the sun in such a way that the reflected radiation is concentrated on receiver absorber on top of a tower. The mirrors are called heliostats.

Central receiver can achieve temperature up to 1000C.

5.2.1.3 Evacuated Tube Collector

Figure.5.3 Evacuated Tube Collector

A type of solar collector that can achieve high temperatures, in the range (77°C) to (177°C) and can, under the right set of circumstances, work very efficiently. Evacuated-tube collectors are, however, quite expensive, with unit area costs typically about twice that of flat-plate collector.

An evacuated-tube collector consists of parallel rows of glass tubes connected to a header pipe. Each tube has the air removed from it to eliminate heat loss through convection and radiation. Evacuated-tube collectors fall into two main groups.

A. Direct-flow evacuated-tube collectors

These consist of a group of glass tubes inside each of which is a flat or curved aluminum fin attached to a metal (usually copper) or glass absorber pipe. The fin is covered with a selective coating that absorbs solar radiation well but inhibits radiative heat loss. The heat transfer fluid is water and circulates through the pipes, one for inlet fluid and the other for outlet fluid. Direct-flow evacuated tube collectors come in several varieties distinguished by the arrangement of these pipes.

1. Concentric fluid inlet and outlet (glass-metal). These use a single glass tube. Inside this is a copper heat pipe or water flow pipe with attached fin. This type of construction means that each single pipe can be easily rotated to allow the absorber fin to be at the desired tilt angle even if the collector is mounted horizontally. The glass-metal design is efficient but can suffer reliability problems. The different heat expansion rates of the glass and metal tubes can cause the seal between them to weaken and fail, resulting in a loss of vacuum. Without a vacuum, the efficiency of an evacuated-tube collector is no better, and may be worse than, that of a flat-plate collector.

2. Separated inlet and outlet pipes (glass-metal). This is the traditional type of evacuated-tube collector. The absorber may be flat or curved. As in the case of the concentric tube design, the efficiency can be very high, especially at relatively low working temperatures. The weakness again is the potential loss of vacuum after a few years of operation.
3. Two glass tubes fused together at one end (glass-glass). The inner tube is coated with an integrated cylindrical metal absorber. Glass-glass tubes are not generally as efficient as glass-metal tubes but are cheaper and tend to be more reliable. For very high temperature applications, glass-glass tubes can actually be more efficient than their glass-metal counterparts

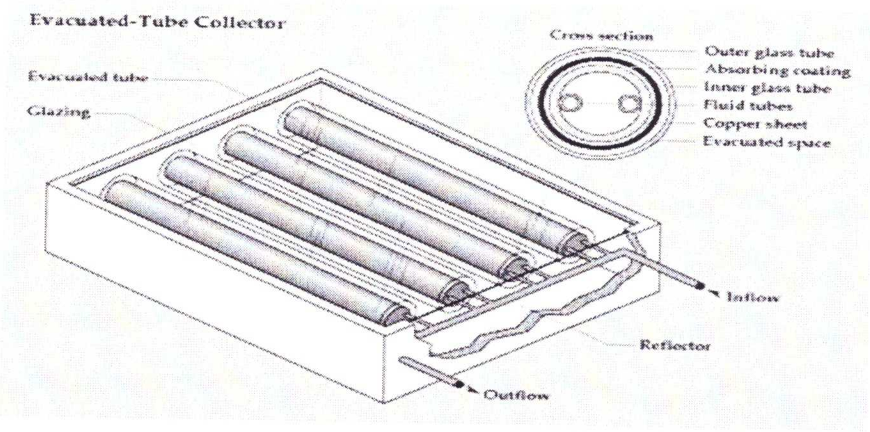


Figure 5.4 Direct-Flow Evacuated-Tube Collectors.

B. Heat pipe evacuated-tube collectors

These consist of a metal (copper) heat pipe, to which is attached a black copper absorber plate, inside a vacuum-sealed solar tube. The heat pipe is hollow and the space inside, like that of the solar tube, is evacuated. The reason for evacuating the heat pipe, however, is not insulation but to promote a change of state of the liquid it contains. Inside the heat pipe is a small quantity of liquid, such as alcohol or purified water plus special additives. The vacuum enables the liquid to boil (i.e. turn from liquid to vapor) at a much lower temperature than it would at normal atmospheric pressure. When solar radiation falls the surface of the absorber, the liquid within the heat tube quickly turns to hot vapor rises to the top of the pipe. Water, or glycol, flows through a manifold and picks up the heat, while the fluid in the heat pipe condenses and flows back down the tube for the process to be repeated.

An advantage of heat pipes over direct-flow evacuated-tubes is the "dry" connection between the absorber and the header, which makes installation easier and also means that individual tubes can be exchanged without emptying the entire system of its fluid.

Some heat pipe collectors are also supplied with a built in overheat protection when a programmed temperature has been reached, a "memory metal" spring expands and pushes a plug against the neck of the heat pipe. This blocks the return of the condensed fluid and stops the heat transfer.

A drawback of heat pipe collectors is that they must be mounted with a minimum tilt angle of around 25° in order to allow the internal fluid of the heat pipe to return to the hot absorber.

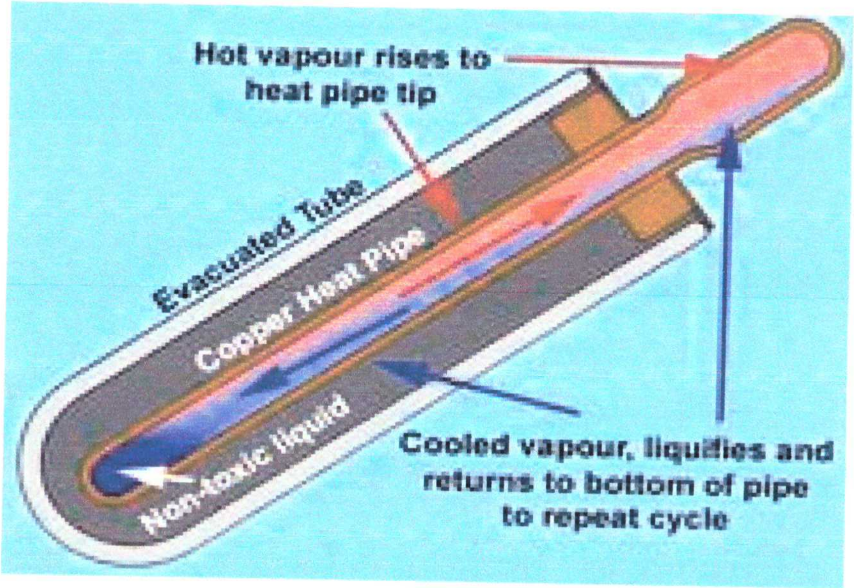


Figure.5.5 Heat Pipe Evacuated-Tube Collectors.

Each tube contains a sealed copper pipe (heat pipe). The pipe is then continuously bonded to a selectively coated copper fin (absorber plate) that collects solar energy, converting it to heat. This energy is conducted to the heat pipe's working fluid, vaporizing it. The vapor rises into a condenser bulb at a higher elevation, and the condensate returns to the collector heat zone by gravity (without a capillary wick structure). The selective coating has an absorbtivity in excess of 92%

throughout the solar spectrum and an emissivity of less than 6% throughout the infrared spectrum (373 K). The coating is applied by a sputtering manufacturing process in a high-vacuum chamber and involves three stages:

1. A stabilizing layer of titanium (Ti).
2. Reaction of the titanium with oxygen, creating a semiconductor layer to absorb radiation.
3. An antireflection coating layer.

Finally, evacuated-tube collectors, unlike flat-plate collectors (the surface of which is always warm), do not shed snow. Because the evacuated tubes are such good insulators, little heat escapes them and the snow that accumulates on the tubes can stick for a long time.

Their surface is also irregular, so snow packs between the tubes, rendering them ineffective, and the fragility of the glass tubes makes it impossible to scrape the a accumulated snow off. [24]

5.3 Design of the PV-Power System (PVPS)

5.3.1 Photovoltaic:

Photovoltaic (PV) cells are semiconductor devices, usually made of silicon, which contain no liquids corrosive chemicals or moving parts. They produce electricity as long as light shines on them, they require little maintenance, do not pollute and they operate silently, making Photovoltaic (PV) energy the cleanest and safest method of power generation.

5.3.2 Background

Photovoltaic (PV) provide powerful solution to today's energy needs. Clean , reliable , durable and cost effective , PV harnesses the power of the sun for use with amplitude of applications .Around the world , remote homes, communications stations , lighting system , the sun powers navigational equipment and entire village .

Oil supplies and price may fluctuate, but the sun always shines. Solar is renewable energy source; there will always be more available. In fact in 40 minutes, the United States receives more energy in the form of sunlight than it does from the fossil fuels it burns in a year. [25]

In our country the total solar radiation received in Palestine (Gaza Strip and West Bank) for the twelve months period is 2016 Kwatt-hour / square meter. While , the average irradiance (insulation) per square meter over the whole twelve month period is 230 watt/ square meter . [26]

Solar does not damage the land or environment where it is located.

It is easily installed directly at the point of application, where the energy is needed, or on the ground, easily blending into the surrounding habitual. Hydroelectric, nuclear and fossil fuel power plants require vast amounts of land; their damming, emissions, waste and cooling can harm the surrounding habitual.

Moreover, the sun energy is free, countries and individuals do not need to purchase fuel for solar system or depend on fuel supplies from unreliable sources.

Solar is free, plentiful, nonpolluting reliable source of energy for today and tomorrows energy needs.[27]

5.3.3 How PV Cells Work

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load

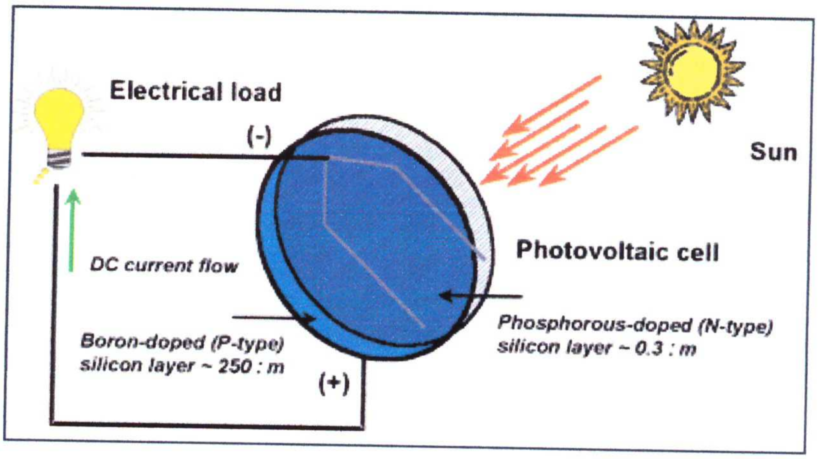


Figure.5.6. PV Cells Work

Regardless of size, a typical silicon PV cell produces about 0.5 – 0.6 volt DC under open-circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional to the intensity of sunlight striking the surface of the cell. For example, under peak sunlight conditions a typical commercial PV cell with a surface area of 160 cm^2 (~25 in^2) will produce about 2 watts peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 0.8 watts.

5.3.4 Types of PV Cells

1. Monocrystalline Silicon Cells

Made using cells saw-cut from a single cylindrical crystal of silicon, this is the most efficient of the photovoltaic (PV) technologies. The principle advantage of monocrystalline cells are their high efficiencies, typically around 15%, although the manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.

2. Multicrystalline Silicon Cells:

Made from cells cut from an ingot of melted and recrystallised silicon. In the manufacturing process, molten silicon is cast into ingots of polycrystalline silicon, these ingots are then saw-cut into very thin wafers and assembled into complete cells. Multicrystalline cells are cheaper to produce than monocrystalline ones, due to the simpler manufacturing process. However, they tend to be slightly less efficient, with average efficiencies of around 12%., creating a granular texture.

3. Thick-film Silicon:

Another multicrystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, this is encapsulated in a transparent insulating polymer with a tempered glass cover and usually bound into a strong aluminum frame.

4. Amorphous Silicon:

Amorphous silicon cells are composed of silicon atoms in a thin homogenous layer rather than a crystal structure. Amorphous silicon absorbs light more effectively than crystalline silicon, so the cells can be thinner. For this reason, amorphous silicon is also known as a "thin film" PV technology. Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes it ideal for curved surfaces and "fold-away" modules. Amorphous cells are, however, less efficient than crystalline based cells, with typical efficiencies of around 6%, but they are easier and therefore cheaper to produce. Their low cost makes them ideally suited for many applications where high efficiency is not required and low cost is important.

5.3.5 Pumps

The solar water pump that are currently available make use of the following motor technologies:-

1. Brushed type permanent magnet D.C motors.
2. Brush less permanent magnet D.C motors.
3. A.C motors.

The use of an A.C motor in a solar pump requires an inverter, which introduces additional costs and some energy losses . Hence A.C motors have not been seriously suggested for low power (less than 250w) applications where the increased cost may be a significant proprtion of the overall cost.A.C motor are generally less efficient than D.C motors.

And this is the Definition of pumps parameter

A. Power:

The cost of pumping or lifting water is closely related to the rate at which power is used. "Means the energy requirement in a given period." And since there is often confusion on the meaning of the "power" and "energy", it is worth also mentioning that the energy requirement consists of aproduct of power and time.

The hydraulic power required to pump water, is afunction of both, the apparent vertical height lifted, and the flow rate at which water is lifted.Which is given by equation.

Where the power can be defines as the rate at which work is done.

Tow kinds of power can be defined:

1. Array input power:

This is calculated as the product of the measured array current, and array voltage produced by the PV array simulator, (when an external load is connected).

$$Pin = V*I*\Phi \ [W] \quad (5.1)$$

Where:

V: voltage [V].
I: current [A].
Φ: phase shift= cos90=1.

2. Hydraulic power output, Ph:

This is the useful hydraulic power developed by the system. The calculation of this number neglects the kinetic energy of the water at the pump outlet, and is based only on the potential energy gained by virtue of the increased in pressure.

$$P_h = H\rho g * Q \qquad (5.2)$$

Where:

H: head [m].
ρ: density of water 1000[Kg/m^3].
g: acceleration due to gravity 9.806 [m/s^2].
Q: flow rate [m^3/s].

B. Head:

The head has a proportional effect on the energy and power requirements with the result that it is cheaper to pump water through lower head. Where the altitude will affect the ability of a suction pump to pull water, as the atmospheric pressure is less at higher altitudes. It consists of two parts:

1. The static head or height through which the water must be lifted.
2. Dynamic head, which is the pressure increase, caused by friction through the pipe work, expressed as an equivalent height of water.

Where the friction head consists of a resistance to flow caused by viscosity of the water and turbulence in the pump or pipes. The velocity head us the apparent resistance to flow caused by accelerating the water form rest to a given velocity through the system.

The equivalent head (m), can be defined as the height of the water column that would correspond to the pressure at pump outlet under standard conditions. If there is a vertical separation between the water surface in the tank and the pressure gauge, the extra pressure component due to this should be added to the head derived form the measured pressure, so:

$$h = h_t + (10^5 * P)/\rho g \tag{5.3}$$

Where:

h: equivalent head[m].

h_t: vertical distance of pressure sensor above pump outlet [m].

P: pressure as measured [bar].

ρ: density of water 1000[Kg/m^3].

g: acceleration due to gravity 9.806 [m/s^2].

The theoretical head of the pump can be calculated from the following equation:

$$H = H_{max} (1-(Qmax/Q)^2) \tag{5.4}$$

Where:

H: theoretical head[m].

H_{max}: max head of the pump [m].

Q: flow rate [m^3/s].

Qmax: max flow rate [m^3/s].

C. Efficiency :

The actual power and energy needs are always greater then the hydraulic energy needs, because losses inevitably occur when producing and transmitting power or energy due to friction. The smaller the friction losses, the higher the quality of a system, where the quality of a system in terms of minimizing losses is defines, as it is “efficiency”.

$$\text{Efficiency} = \text{Hydraulic power output} / \text{Array input power (actual)} \qquad (5.5)$$

A truly frictionless pumping system would in theory be 100% efficient, but there are always friction losses associated with every mechanical and hydraulic process.

There are two types of efficiency:

1. Power efficiency of the sub-system, which is the ratio of hydraulic output power to array input power, at any instant in time.
2. Energy (or daily) efficiency of the sub-system, which is the ratio of hydraulic output energy to electrical input energy over a day.[28]

5.4 Testing and There Performance

The short term performance testing in this project depend on the following equations of this method are showing in section.

5.4.1 Collector Thermal Performance Testing

5.4.1.1 Testing Method:

The transient response of the thermosyphon collector and the change of the heat transfer fluid flow rate with the change in the incident irradiance, represent the difficulties associated with the development of a standard test procedure for testing thermal performance such system. However, the method used to test collector operating with constant flow rate is the steady-state method. The method was first proposed by Hill and kausuda (1974), and the published by ASHRAE standard {1974}and latter ANSI/ASHRAE 93-2003. The method has been adopted for use by the international energy (IEA) and the European commission (1980) working groups. Later the British standard institution has published the method in BS 6757: (1986) in which recommendation for attesting procedure using the solar simulator was included.

The steady state testing method depends on measuring the instantaneous parameters of collector should correspond stationary conditions over a period of 15 to 20 minutes. A straight line presentation could then be plotted using the relationship:

$$\eta = \eta_{\circ} - U T^{*} \tag{5.6}$$

Where: -

η :Derived value of collector efficiency for steady indoor conditions, dimensionless .

T^* : is the reduced temperature different; which takes the form:

$$T^* = (T_m - T_a)/G_T \tag{5.7}$$

The mean plate operating temperature Tm is given by:

$$T_m = (Ti+Te)/2 \tag{5.8}$$

The slope U in the equation (3.6) represents the collector heat loss coefficient. The intercept with the Y axis η_o is the collector heat loss efficiency or the optical efficiency.

5.4.1.2 Energy of Collectors:

The energy output of the collectors is calculated as:

$$Q_{out} = \dot{m}_C \, C_P (T_e - T_i) \tag{5.9}$$

Where :

T_e :Water exist temperature, ° C

T_i :Water inlet temperature, ° C

$$Q_{in} = G_T \, A_C \tag{5.10}$$

Q_{in} : Energy input into the system, MJ

G_T : Equivalent normal solar irradiance on a collector plane, w/m^2 .

A_C : Aperture area of the collectors, m^2

The resulting of instantaneous efficiencyη, is represented by the ratio of the output to the input (Q_{out} / Q_{in}).

5.4.1.3 Energy collected by More than One Collectors Connected in Series

When tow collectors or more (the same type) are connected in series , by using the Duffie and backman correlations the new resulting parameters can be given as :

$$\eta_{o\,new} = \eta_o \left(1 - \frac{k}{2}\right) \tag{5.11}$$

$$U_{new} = U \left(1 - \frac{k}{2}\right) \tag{5.12}$$

where k is given by :

$$k = \frac{UAc}{\dot{m}_C\, Cp} \tag{5.13}$$

The area of collectors (Ac) playing the role in new equations for multiple collectors in series.

5.4.2 Testing for (PV) Cells

Test one:

This test is obtained to get irradiance daily data, corresponding to the PV cells, that is connected to the motor-pump, that could work up the pump.

The following procedure is obtained:

1. The circuit is connected as figure.5.7.
2. Then the pump start up to work at the morning, all readings of flow rate, pressure , current, and voltage are will record.
3. These reading of data, are repeated every (15 to 20) minutes, along the day, until the pump stop working, as power decreases at evening.
4. This procedure is obtained for three cases:
   - When the valve of the pipe is full open.
   - When the valve is half open.
   - When the valve partially open.

Every case is obtained for two days data.

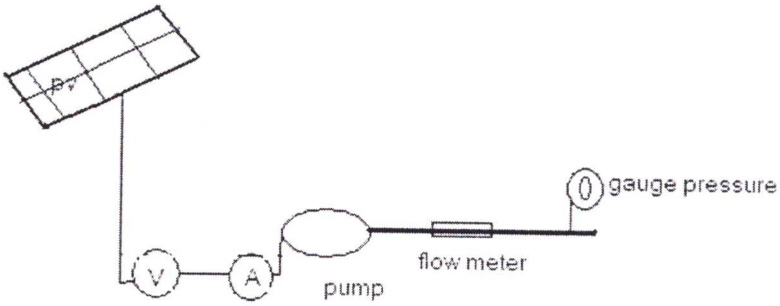


Figure 5.7 Schematic Diagram for PV Pumping System.

Test two:

This test is obtained to determine the performance of the pump used, as connected to the pv cells, and also to determine the pump daily efficiency, at different points of time.

The following procedure is obtained:

1. the circuit is connected as figure 5.7
2. as the pump start up to work, as the input power array increased, when the valve is full open, "which means, that the gauge pressure reads zero, because of the release of pressure to the atmosphere", all other reading of flow rate, current, and voltage are recorded down.
3. At the same time, when the step 2 is obtained, the valve is adjusted as the pressure gauge reads (0.2, 0.4, 0.6, 0.8, 1...) bar, until three pump stop working because of the high load.
4. To find the maximum pressure that the pump could obtain at that instant of test, the following procedure is recommended:
   - The valve must be open at full option.
   - The pump must turns off, by separate the wire of the pv cells.
   - The valve is again closed to the full position.
   - Then the pump again turns on by connection of pv wire.
   - After of that, the maximum pressure could be obtained from the gauge pressure.

But this reading of maximum pressure should be quickly taken.

Chapter six 6

Description of a Desalination System Based On Combining Solar Energy with Membrane Module Technology.

Contents:

Chapter six

Description a Desalination System Based On Combining Solar Energy with Membrane Module Technology.

6.1 Introduction

The hole of the desalination system which is combining between solar energy and membrane technology performed the desired purpose of the desalination process throughout a three subsystems, and these subsystems integrated in there work as illustrated in the figure.6.1.

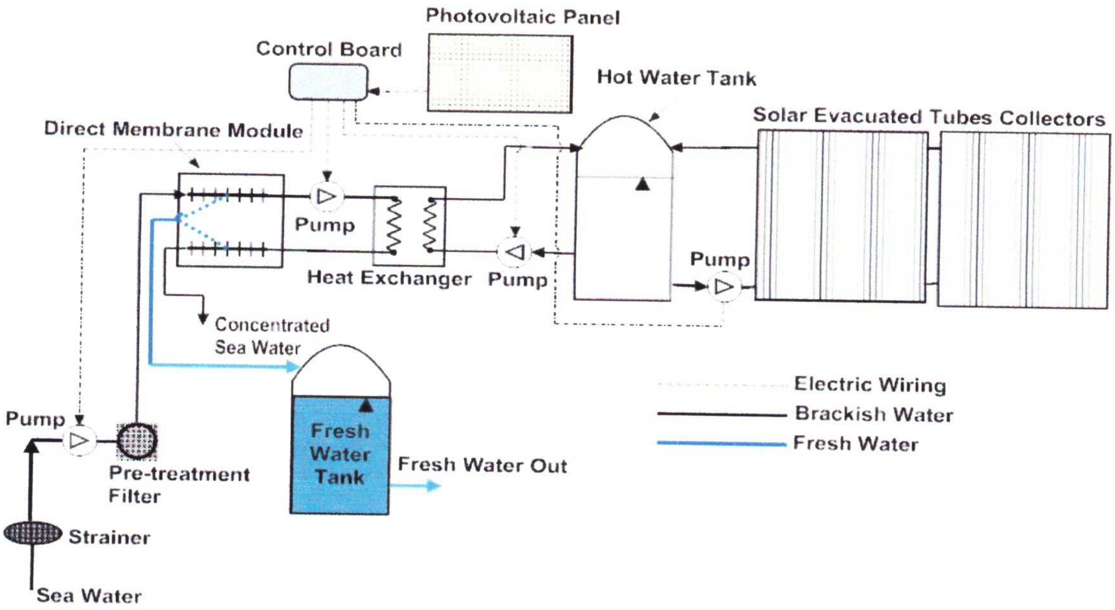


Figure. 6.1 Combined Desalination System Unit.

The previous subsystems are:

1. The first subsystem: This subsystem is used to carry out the salt water and passes it through arrangement of strainers, pumps, pipes, filters, heat exchanger to increase the temperature of the working water, membrane module to take a fresh water at the end point of this subsystem.

2. The second subsystem: This subsystem is used to deliver heat energy to the first subsystem through heat exchanger, by converting a solar energy to heat energy through arrangement of evacuated tubes, the heat carried to the heat exchanger by arrangement of pumps, pipe, and hot water tank.

3. The third subsystem: This subsystem is used to produce an electrical energy which is to derive the pumps in the system, by converting a solar energy to electrical energy through arrangement of photovoltaic cells, using wires, and control board to perform this function.

6.2 Components of the First Subsystem

1. Strainer: This device is used to separate the impurities and other small solid objects from the salt water which is go to desalination cycle, and the strainer selection depends on the volume of the impurities and solid objects, and also on the concentration of the salt.
2. Pump: The pump used in this system must provide an operating pressure which is adjusted to overcome the adverse effects of the following:

- Osmotic pressure
- Friction losses like pipe and elbow loses, filter loses, membrane loses...etc.
- Membrane resistance
- Permeate pressure

If the operating pressure is set equal to the sum of the above resistances the net permeate flow rate across the membrane would be minimal or equal to zero; therefore, the operating pressure is set at higher value in order to maintain economical permeate flow rate.

The previous listed term of osmotic pressure that the pump must overcome it is controlled by the salt concentration in the water, and the pump operating pressure must be generated according to the salt concentration as follows:

- For brackish water, the pump operating pressure requirement is between 20 and 60 Kpa.(explained later in chapter seven)
- For seawater, pumps may need to generate up to 176 Kpa.

The selection of the pump in this system depends on there operating pressure, cost, material of the pump which is act as resistance to erosion and harshness; there is a secondary pump used in a different location in the system to maintain the operating pressure at a desired value. And the project selects the centrifugal pump (will be mention later in chapter seven).

3. Pre-treatment filter: This device represent a secondary stage of filtration while the strainer is the first stage, this type of filters used to remove a micorimpurities, bacteria, and another objects that the strainer cannot remove it. The selection of this device depends on the cost, the degree of purity of salt water.

4. Pipe: This equipment used to connect system elements to each other, and the material of this pipe may be many type like Copper, plastic, stainless steel. And the selection ofpipe material depends on the following criteria:
    - The ability to withstand under a high pressure generated by the pumps.
    - Resistance to erosion.
    - Isolated to heat transfer.
    - Cost

5. Heat Exchanger: This is an important element in the system which is used to increase the temperature of the working water in the cycle by making transfer the heat coming from the second subsystem which will be explain later.

The amount of the product water and the salt rejection are mainly directly proportional to the operating pressure and temperature, this means that the increase in temperature will increase the efficiency of the whole system.

- Theory of heat exchanger

The used heat exchanger in this system is shell and tube type.

The fundamental equations for heat transfer across a surface are given by heat balance:

$$Q = U\,A\,\Delta T_{lm} = m_1 C_{p\,(t)}\left(t_2 - t_1\right) = m_2\,C_{p(s)}\left(T_1 - T_2\right) \qquad (6.1)$$

Where:

Q: Heat transferred per unit time (kJ/h).

m_1: volumetric flow rate in tube (m^3/s).

m_2: volumetric flow rate in shell side (m^3/s).

U: The overall heat transfer coefficient (kJ/h-m^2 C^o).

A: Heat-transfer area (m^2).

ΔT_{lm}: Log mean temperature difference (C^o).

Cp (t): Liquid specific heat tube side. (KJ/kg. C^o).

Cp (s): liquid specific heat shell side (kJ/kg. C°).

The log mean temperature difference Δ**Tlm** (LMTD) for countercurrent flow is given by:

$$\Delta T_{lm} = \frac{(T_{h2} - t_{c2}) - (T_{h1} - t_{c1})}{\ln \frac{(T_{h2} - t_{c2})}{(T_{h1} - t_{c1})}} \qquad (6.2)$$

Where:

T_{h1}: inlet temperature from evacuated tube.

T_{h2}: outlet temperature to evacuated tube.

T_{c1}: inlet temperature from membrane.

t_{c2}: outlet temperature to the membrane.

In design, a correction factor is applied to the LMTD to allow for the departure from true countercurrent flow to determine the true temperature difference.

$$\mathbf{\Delta Tm = Ft * \Delta Tm} \qquad (6.3)$$

Where:

Ft: correction factor, and usually 0.8 in the heat transfer reference book

ΔTm: true temperature difference (C°)

- Heat Transfer Model Selection

The heat transfer model selection is determined by the heat transfer process (sensible, condensing, boiling), the surface geometry (tube-side, shell-side), the flow regime (laminar, turbulent), and the working water temperature which is desired. [29]

6. Membrane: Is the main component in this system, which is worked according to the reverse osmosis module, the project select the spiral wound type, because this module required only for enough operating pressure to cover osmotic pressure and pressure drop through the cycle, wile another module required chemical or physical (evaporation) processes.

7. Fresh water tank: this element is used to collect the fresh water produced from the membrane.

6.3 Components of the second subsystem

1. Evacuated Tube collectors: This device is used to collect solar energy, then convert it to heat energy stored in the working fluid. The selection of the evacuated tube depends on :
    - The efficiency of the used evacuated tube according to the required heat in the system.
    - Cost.
2. Hot water tank: This device acts as storage of heat energy, and this tank must be high degree of isolation, and the specification of this tank determined by:
    - Insulation degree.
    - Capacity or size (explained in chapter seven).
    - Resistance to corrosion.
    - Cost.
3. Heat Exchanger: represent a connection point between the second subsystem which is used to produce the heat and the first subsystem which take this produced heat.

6.4 Components of the Third Subsystem

The aim of this subsystem is to provide each element in the system by the electrical energy if required it, like pumps, sensors, control board. The components of this subsystem are:

1. Photovoltaic cells (PV): This device is used to collect solar energy, then convert it to electrical energy, the used PV in this system is Silicon cells, and the selection of PV is determined by :
    - The efficiency of the used PV according to the required electrical energy in the system.
    - Cost.

2. Control board: This device is used to receive electrical energy from PV, then control and distribute it to system equipments, and the selection of control board mainly depends on the cost.

3. Wire connection: to carry the electrical current to system equipment, and the selection of it depends on:
    - Current resistance
    - Cost.

Chapter Seven 7

Calculations and Selections of the Desalination System.

Contents:

Chapter Seven

Calculations and Selections of the Desalination system.

7.1 Introduction

This chapter will improve desalination system unit through selections and calculations of the unit components.

The calculations generally depends on the purpose of the desalination processes which the purpose is to reach a certain value of the permeate flow rate as a final output of the desalination system unit.

In this project the selection of all components must be provided this desired permeate flow rate to reach nearly from (2.5-3 m^3/day), and the project takes the 2.6 m^3/d as a design reference for the calculations.

The selection of the 2.6 m^3/d as a permeate flow depends on the standard size of membrane which is shown in the table 7.1.

Table 7.1 Seawater RO Membranes in Thin Film Composite are Manufactured by (Filmtec), Hydranautics, Osmonics (Desal) and Toray. [30]

TYPE	Membranes	Diameter	Permeate Flow	Surface	Max pressure	Salt Rejection (NaCl)
FILMTEC	SW30-2540	2.5"	2.6 m3/d	2.6 m2	68.9 bar	99.4%
	SW30-4021	4"	3.0 m3/d	3.1 m2	68.9 bar	99.4%
	SW30-4040	4"	7.4 m3/d	7.4 m2	68.9 bar	99.4%
	SW30HRLE-4040	4"	6.1 m3/d	7.9 m2	82.7 bar	99.75%
	SW30HR-380	8"	23.0 m3/d	35.3 m2	68.9 bar	99.70%
	SW30-380	8"	34.1 m3/d	35.3 m2	68.9 bar	99.40%
Extra low energy	SW30XLE-400i	8"	34.1 m3/d	37.2 m2	82.7 bar	99.70%
	SW30HRLE-400i	8"	28.4 m3/d	37.2 m2	82.7 bar	99.75%
ultra low energy	SW30ULE-400i	8"	41.6 m3/d	37.2 m2	82.7 bar	99.70%
Boron removal	SW30XHR-400i	8"	22.7 m3/d	37.5 m2	82.7 bar	99.75%
DESAL	AD 2540 FF	2.5"	1.4 m3/d		68.9 bar	
	AD 4040 FF	4"	4.7 m3/d	8.2 m2	82.7 bar	99.6%
	AD 8040F	8"	20.8 m3/d	34.8 m2	82.7 bar	99.6%
HYDRANAUTICS	SWC1-4040	4"	4.5 m3/d	6.5 m2	68.9 bar	99.5%
	SWC3+	8"	26.5 m3/d	37.2 m2	82.7 bar	99.8%
	SWC4+	8"	24.6 m3/d	37.2 m2	82.7 bar	99.8%
	SWC5	8"	34.1 m3/d	37.2 m2	82.7 bar	99.8%
TORAY	TM810	4"	4.5 m3/d	7.0 m2	68.9 bar	99.75%
	TM820-370	8"	23.0 m3/d	34.0 m2	68.9 bar	99.75%
	TM820-400	8"	25.0 m3/d	37.0 m3	68.9 bar	99.75%
	TM810L	4"	6.0 m3/d	7.0 m2	68.9 bar	99.70%
	TM820L-370	8"	34.1 m3/d	34.0 m2	68.9 bar	99.70%
	TM820L-400	8"	37.9 m3/d	37.0 m2	68.9 bar	99.70%

In previous membrane modules the used recovery ratio between (40% - 60%), and the effective operation hour per day almost equal 8 hours.

In this project the membrane module chosen with a certain geometry to have a recovery ratio equal (50%), and from the table 7.1 the chosen membrane have a permeate flow rate equal 2.6 m^3/d, ($9.03*10^{-5}$ m^3/s) , then the feed flow rate that must be enters the desalination cycle obtained by the equation (4.1)

$R_p = 100\% (Q_p/Q_f)$

Then:

$Q_f = Q_p / R_p *100\%$

$= 2.6/0.5 = 5.2 \ m^3/d = 1.81*10^{-4} \ m^3/s$

Note: assume the diameter of pipes in cycle is selected from the manufacturing standard pipes which are equal to 1 inch, (2.54 cm), and made of cast iron which have roughness equal to 0.203 , see Appendix A (A-1).

The following figure (7.1) Illustrate the components of the desalination unit that consists of three subsystem.

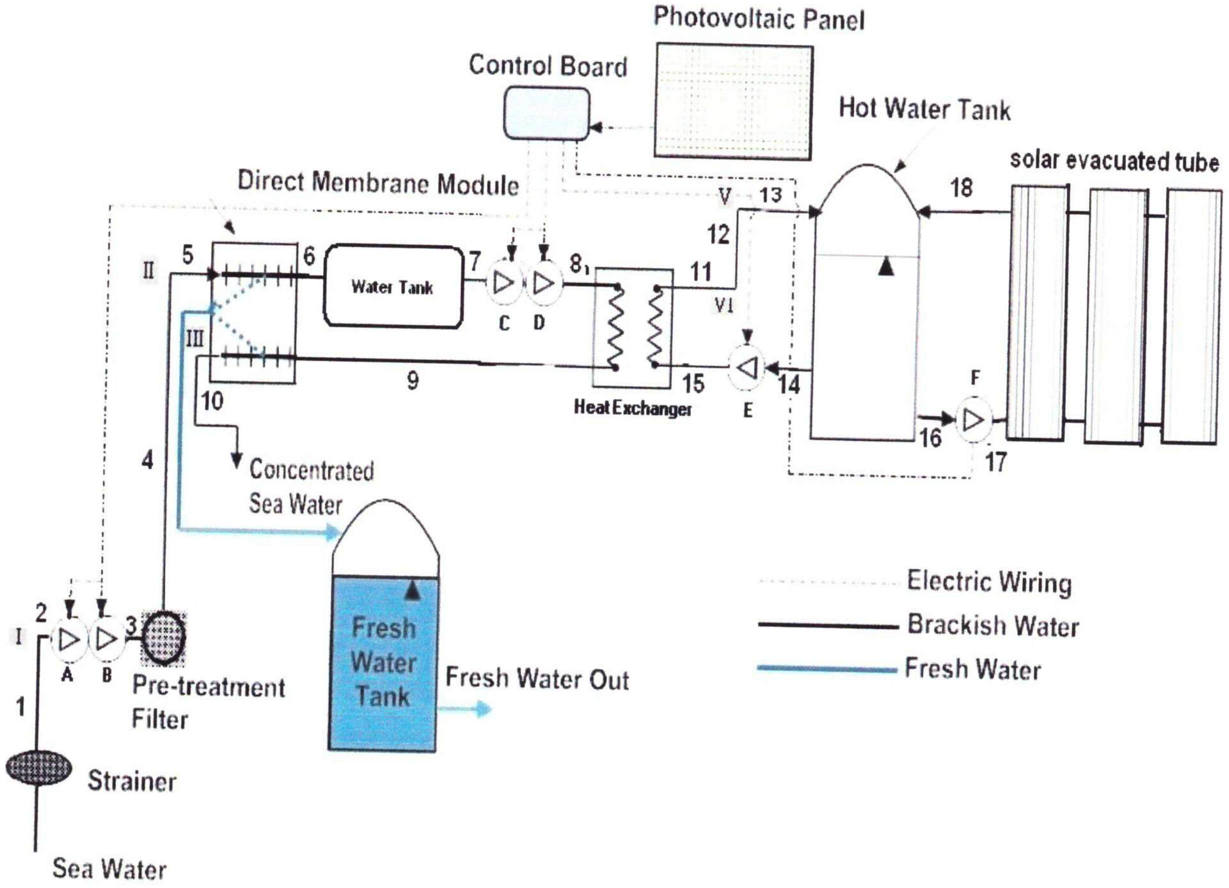


Figure 7.1 Schematic Diagram of the Desalination System Unit

7.2 Calculations and Selections of The First Subsystem Component.

7.2.1 Head losses In Pipes

Table 7.2 Loses Through First Subsystem Pipe

Pipe #	Type	ε (mm)	D (m)	ε/D	L (m)	V (m/s)	Q (m^3/s)	Re	f	h_f (m)
1	Cast Iron	0.203	0.0254	0.008	5	0.35	$1.81*10^{-4}$	9184	0.041	0.053
2	Cast Iron	0.203	0.0254	0.008	2	0.35	$1.81*10^{-4}$	9184	0.041	0.020
3	Cast Iron	0.203	0.0254	0.008	2	0.35	$1.81*10^{-4}$	9184	0.041	0.020
4	Cast Iron	0.203	0.0254	0.008	10	0.35	$1.81*10^{-4}$	9184	0.041	0.100
5	Cast Iron	0.203	0.0254	0.008	1	0.35	$1.81*10^{-4}$	9184	0.041	0.010
6	Cast Iron	0.203	0.0254	0.008	1	0.35	$1.81*10^{-4}$	9184	0.041	0.010
7	Cast Iron	0.203	0.0254	0.008	2	0.26	$1.35*10^{-4}$	6822	0.044	0.012
8	Cast Iron	0.203	0.0254	0.008	2	0.26	$1.35*10^{-4}$	6822	0.044	0.012
9	Cast Iron	0.203	0.0254	0.008	4	0.26	$1.35*10^{-4}$	6822	0.044	0.024
10	Cast Iron	0.203	0.0254	0.008	5	0.178	$0.902*10^{-4}$	4671	0.047	0.015

In the table 7.2 the flow rate through the pipe as follow:

- Pipes (1,2,3,4,5) have a flow rate equal to the feed flow rate which equal to $1.81*10^{-4}$ m^3/s.
- Pipes (6,7,8) have a flow rate equal to feed flow rate minus fifty percent of the desired permeate flow rate :

  $Q= Q_f - 0.5Q_p = 1.35*10^{-4}$ m^3/s.
- Pipe (9) has a flow rate equal to feed flow rate minus permeate flow rate:

  $Q = Q_f - Q_p = 0.902*10^{-4}$ m^3/s.

Then :

The velocity through each pipe in the cycle is obtained by :

$$V_i = Q_i / A_i \tag{7.1}$$

Where :

V_i : is the velocity through the pipe.

Q_i : is the flow rate through the pipe.

A_i : is the cross sectional area of the pipe.

From the Moody chart , Appendix A (A-3) ,the head losses through each pipe obtained as follow:

1- Calculate the Reynolds number (Re) in each pipe:

$$Re = \rho v_i D / \mu \tag{7.2}$$

Where :

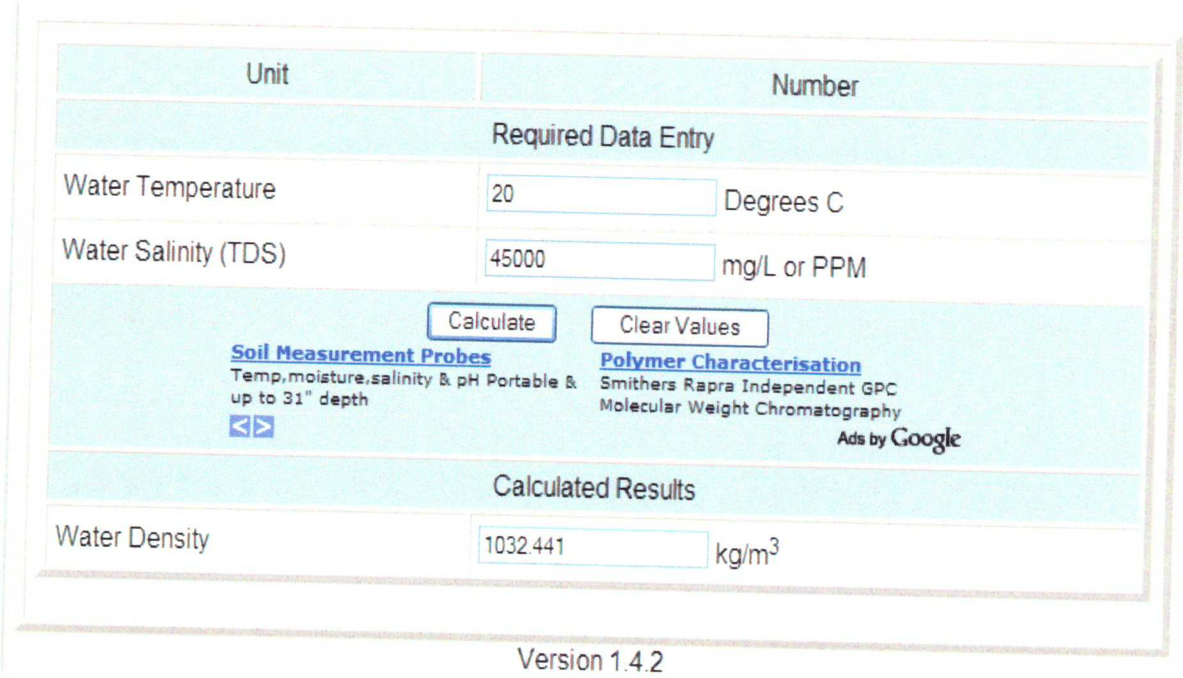
μ :coefficient of absolute viscosity of the fluid (N.s/m^2) , obtained from table 7.4

ρ: density of water (kg /m^3) , obtained from software data that shown in figure 7.2

D: diameter of pipe (m)

The density of pure water is 1000 kg/m^3 , From Appendix A (A-2) , There are two main factors that make pure water more or less dense than about 1000 kg/m^3, The first is the temperature of the water and the other is the salinity of the water.

So the calculation of the water density with several salt concentration and several temperature performed by the software program shown in figure 7.2.



Unit	Number
Required Data Entry	
Water Temperature	20 Degrees C
Water Salinity (TDS)	45000 mg/L or PPM
Calculated Results	
Water Density	1032.441 kg/m^3

Figure 7.2: Calculation of Water Density [31]

2- Calculate the ratio ϵ/D for each pipe.

Where:

ϵ : is the hydraulic roughness which depends on pipe material (mm) .

D: is the diameter of the pipe (mm).

3- From the moody chart at a certain values of (ε/D) and (Re) ,the friction factor is obtained.

4- The head losses through the pipe is obtained as follows:

$h_f = f\,LQ^2/12D^5$ (7.3)

Where :

L: is the length of the pipe.

For example for pipe number 1 the head losses calculated by equation 7.3:

$h_f = 0.041*5*(1.81*10^{-4})^2 / 12\,(0.0254)^5$

$= 0.053m$

7.2.2 Head losses in fittings

Table 7.3 Head Losses in Fittings

Fittings #	Type	K	V (m/s)	Q (m^3/s)	h_f (m)
I	Elbow90°	2	0.35	$1.81*10^{-4}$	0.012
II	Elbow90°	2	0.35	$1.81*10^{-4}$	0.012
III	Elbow90°	2	0.178	$0.902*10^{-4}$	0.0032

The head losses through fittings obtained as follow:

$$h_f = k\,(v^2/2g) \qquad (7.4)$$

Where:

K: the fitting constant which depends on the fitting degree [32]

For example for fitting number I the head losses is obtained by equation 7.4 :

$$h_f = 2\,(0.35^2 / 2 * 9.82)$$

$$= 0.012$$

7.2.3 Strainer

The strainer selection depend on many parameters which determined the head loses through and the parameter is:

- Materials of construction of the strainer :

- Aluminum
- Cast Iron
- Ductile Iron
- 316 Stainless Steel

- Geometry : Generally obtained by the diameter of the strainer.

This project select (Lid-Ease® Basket Strainer) which have a performance specifications

Shown in the table 7.4

Table 7.4 Performance Specifications of Strainer (Lid-Ease® Basket Strainers).

Capacity	0 - 340 m³/hr
Pressure	0 - 70 bar
Viscosity	$5x10^{-4}$ - $1.5x10^{-3}$ N.s/m²
Temperature	10 - 60 C°

The calculation of head loses for the strainer need a selection of diameter

And then from figure (7.3) find strainer resistance (k).

The diameter of strainer selected is 2inch (5.08cm)

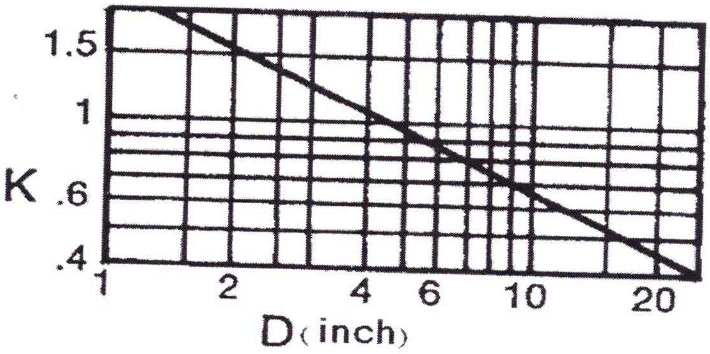


Figure 7.3 Resistance Coefficient in The Basket Strainer .

The velocity through strainer obtained from the continuity equation as:

$V= Q_f /A$

Where :

A : is the cross sectional area of the strainer.

Then:

$V=1.81*10^{-4} / 2.02*10^{-3} = 0.089$ m/s

Then:

The head loses in the strainer is obtained by equation (7.4) :

$h= k(v^2/2g)$

Where:

h = head loss in meter
K = resistance coefficient = 1.5 from figure 7.3
V = velocity in strainer
D = diameter of strainer
$g = 9.82$ m/s^2

$h=1.5 *(0.089^2 /2*9.81) =6*10^{-4}$ m

7.2.4 Pretreatment Filter

The selection of pretreatment filter depends on the flow rate through it and the size of impurities must separated .

The main duty of filter is to remove insoluble and suspended material and should be with chemical treatment to have :

- Clean and non toxic water
- Tasteless and odorless
- Free bacteria and algae
- Ph balanced to prevent corrosion and scale formation

This project selects a (R3F Filters using Milspec 13 Glass Beads) which has a flow rate of (2-15gpm) and ability to separate impurities with size of (0.15 μm – 5 μm).

At flow rate through filter which equal to the feed flow rate ($1.81*10^{-4}$ m^3/s), Which equal (2.86 gpm).

Then:

The head losses through the pretreatment filter is calculated from the following chart.

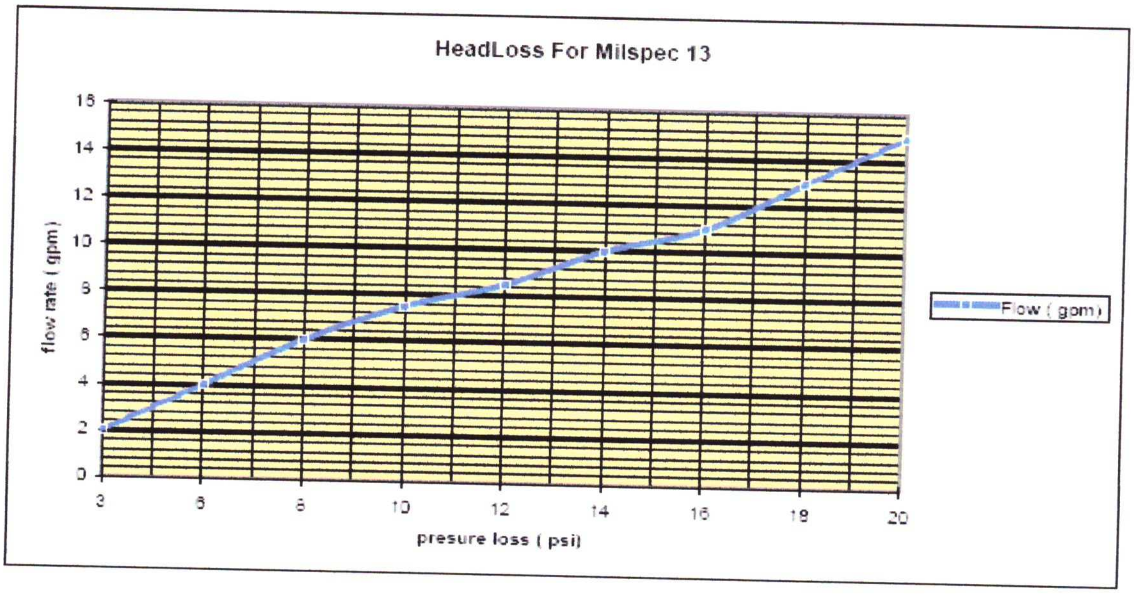


Figure 7.4 Head Losses For R3F Filters Using Milspec 13 Glass Beads.

From the chart the pressure losses in pretreatment filter at flow of 2.86 gpm is equal to 3.7 psi.

Then :

The head losses 3.7*0.7 =2.6 m

7.2.5 Membrane

In this project the membrane selected from table 7.1 which has a code (SW302540) , it has a maximum resistance appears due to osmotic pressure $\Delta\pi$, and transmembrane pressure (resistance pressure) Δp , equal to 68.9 bar (688 as head loss).

Another way to fined the maximum resistance in membrane by Appling steps :

Step 1 :

Fined transmembrane pressure (resistance pressure) Δp :

This element has a head loss which is equal to Δp shown in the figure (7.5) which is calculated empirically by a simple instrument (manometer).

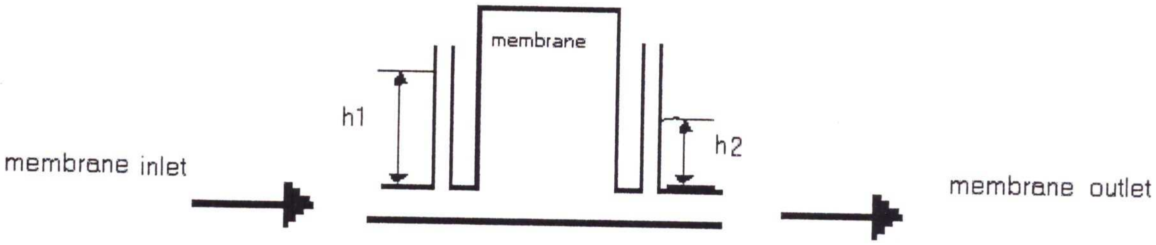


Figure 7.5 Head Losses Through The Membrane.

Then:

$$\Delta p = \rho g(h_1-h_2) \quad (7.5)$$

Where:

ρ : is the desity of water flow throuh membrane,(kg/m^3)

g : acceleration gravity ,(m/s^2)

h_1-h_2 : the pressure head difference , (m)

The membranes shown in the table 7.1 have a resistance range R_m (10^{10}- 10^{15} pa.s/m), and at a certain value of water recovery, then the corresponding transmembrane pressure Δp from figure (7.6) can be obtained .

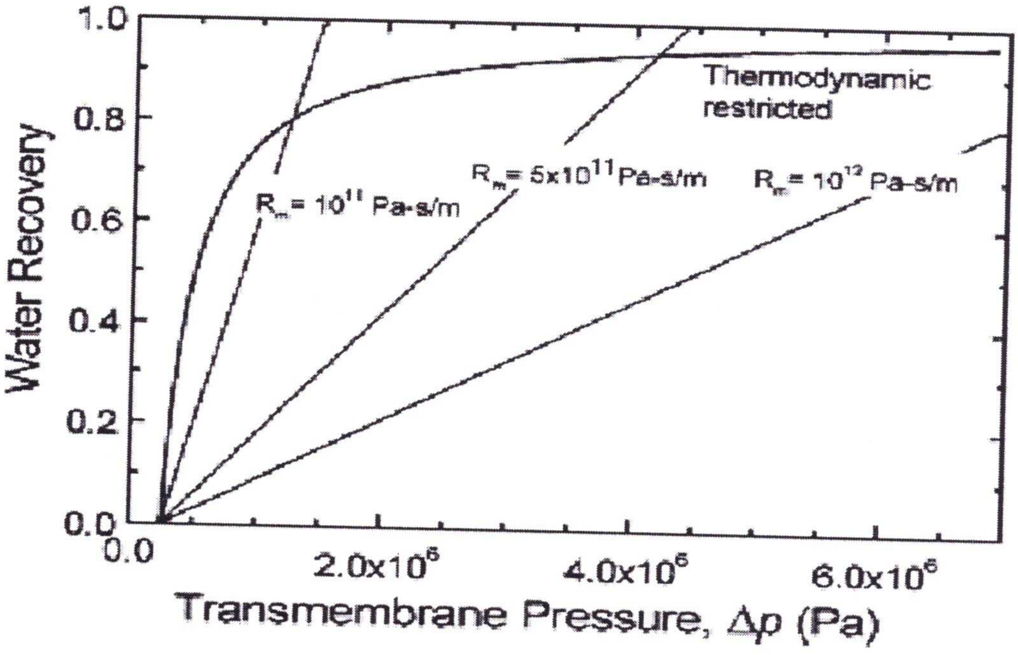


Figure 7.6 Membrane Parameter

Step 2 :

Fined The osmotic pressure difference across the membrane ($\Delta\pi$) is obtained from :

$$\Delta\pi = \pi p - \pi a$$

Where :

$\pi_a = R*T_{(20)}*\Sigma xi$ (feed) and $\pi_p = R*T_{(40)}*\Sigma xi$(brine)

Where:

Σxi (feed) = 45000 part per million(ppm), for sea water , and

Σxi(brine) =45000*2 , (0.50) is the recovery ratio used in membrane.

= 90000 ppm

From an approximation for the osmotic pressure which obtained empirically may be made

By assuming that 1000 ppm of (TDS) equal to 75.84Kpa of osmotic pressure at (300k°)

Then:

$\pi = R*T*\Sigma xi$

$\Sigma xi = \pi / (R*T) = 75.84 / (8.314*300) = 0.03\ Kmol / m^3$

This means that every 1000 ppm equal to 0.03 Kmol / m^3

Then:

$\pi_a = R * T_{(20)} * \Sigma xi$ (feed) $= 8.314 * 293 * (45000 * 0.03) = 3288$ Kpa

and

$\pi_p = R * T_{(40)} * \Sigma xi$ (brine) $= 8.314 * 313 * (90000 * 0.03) = 7026$ Kpa

Then:

$\Delta\pi = (7026-3288) = 3738$ Kpa

Here the membrane have a head losses due to friction(membrane resistance) equal to Δp, and there is another resistance due to difference concentration of flow water $(\Delta\pi)$, where the Operating pressure carried by the pump must cover them.

7.2.6 Heat Exchanger

In this project Shell-and-Tube heat exchanger (counter flow design) is selected.

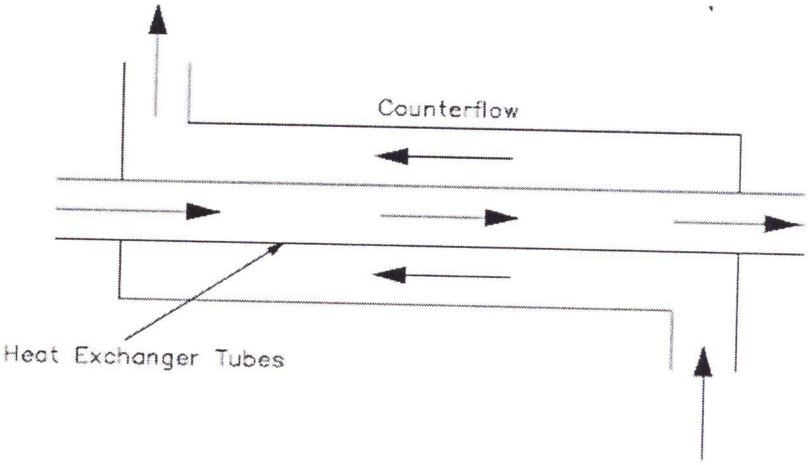


Figure 7.7 Counter Flow Heat Exchanger.

From the energy balance equation in heat exchanger and from membrane volume flow rate ($1.35*10^{-4}$ m^3/s):

$$m_c*Cp_c*(\Delta T_c) = m_h*Cp_h*(\Delta T_h)$$

$\Delta T_c = Tc_2 - Tc_1$

$\Delta T_h = T_{h1} - T_{h2}$

Where:

m_c : is the mass flow rate in the cold side (Kg/s).

m_h : is the mass flow rate in the hot side (Kg/s).

Cp_c : Liquid specific heat in the cold side (kJ/kg. C°)

Cp_h : Liquid specific heat in the hot side (kJ/kg. C°)

Tc_1: Temperature of water at the inlet of the heat exchanger in the cold side .

Tc_2 :Temperature of water at the outlet of the heat exchanger in the cold side.

T_{h1}: Temperature of water at the inlet of the heat exchanger in the hot side.

T_{h2}: Temperature of water at the outlet of the heat exchanger in the hot side.

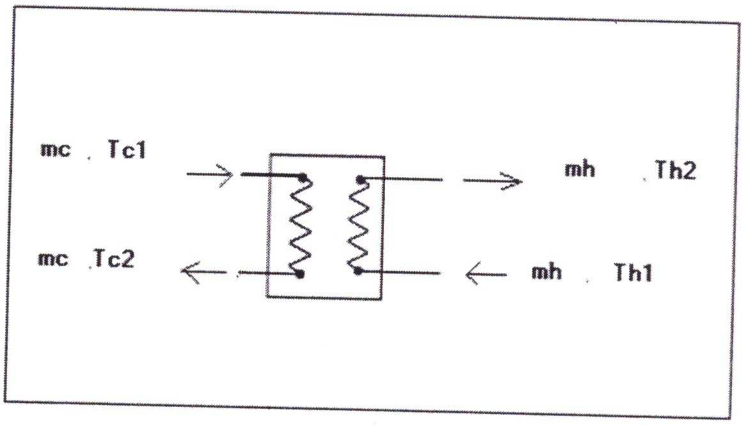


Figure 7.8 Parameters of Heat Exchanger.

Calculations of Heat Exchanger:

The values which desired and taken :

Tc_1=20 C°(ambient temperature)

Tc_2 =40 C° (desired temperature for the membrane)

T_{h1} = 60 C°(according to evacuated tube design)

$m_c = (1.35*10^{-4}\ m^3/s) * 1033\ Kg/m^3 = 0.14 Kg/s$.

m_h = 0.35 Kg/s (selected, comes from hot water tank)

Cp_c and Cp_h to be assumed equal and equal to Cp of the pure water which equal to (4.182 kJ/kg. C°)

By energy balance across heat exchanger T_{h2} can be calculated as :

$$m_c*Cp_c*(\Delta T_c) = m_h*Cp_h*(\Delta T_h)$$

T_{h2} =52 C°

Then the heat power (q) can be calculated from the hot side as :

-Hot side:

$$q = m_h*Cp_h*(\Delta T_h) = 0.35 * 4182 * (60-52) = (11710 \text{ Watt})$$

Also the heat power (q) can be expressed as :

$$q = U\ A\ \Delta T_{lm} \qquad (7.6)$$

And :

$$\Delta T_{lm} = \frac{(T_{h2} - t_{c2}) - (T_{h1} - t_{c1})}{\ln \frac{(T_{h2} - t_{c2})}{(T_{h1} - t_{c1})}}$$

$= (23.25\ C^{o})$

The overall heat transfer coefficient (U) depends on:

-The geometry of the selected heat exchanger

- The material used

- The liquid used

The following table shows approximation values of (U)

Table 7.5 Approximation Values of Overall Heat Transfer Coefficient.

Type	Application and Conditions	*U* W/(m^2 K)[1]	*U* Btu/(ft^2 °F h)[1]
Tubular, heating or cooling	Gases at atmospheric pressure inside and outside tubes	5 - 35	1 - 6
	Gases at high pressure inside and outside tubes	150 - 500	25 - 90
	Liquid outside (inside) and gas at atmospheric pressure inside (outside) tubes	15 - 70	3 - 15
	Gas at high pressure inside and liquid outside tubes	200 - 400	35 - 70
Tubular, condensation	Steam outside and cooling water inside tubes	1500 - 4000	250 - 700
	Organic vapors or ammonia outside and cooling water inside tubes	300 - 1200	50 - 200
Tubular, evaporation	steam outside and high-viscous liquid inside tubes, natural circulation	300 - 900	50 - 150
	steam outside and low-viscous liquid inside tubes, natural circulation	600 - 1700	100 - 300
	steam outside and liquid inside tubes, forced circulation	900 - 3000	150 - 500
Air-cooled heat exchangers[2]	Cooling of water	600 - 750	100 - 130
	Cooling of liquid light hydrocarbons	400 - 550	70 - 95
	Cooling of tar	30 - 60	5 - 10
	Cooling of air or flue gas	60 - 180	10 - 30
	Cooling of hydrocarbon gas	200 - 450	35 - 80
	Condensation of low pressure steam	700 - 850	125 - 150
Plate heat exchanger	Water to water	1000 - 4000	150 - 700

From the previous table the project select water – to- water heat exchanger type ,with U= (1000w/ m2 C°).

The surface area of the heat transfer of the selected heat exchanger obtained as:

$A = q / U \Delta T_{lm}$

Where:

q= 11710Watt

U=1000w/ m2 C°

ΔT_{lm}=23.25 C°

A=0.50 m^2, This area used as guide to select a suitable heat exchanger from standard.

By using the average water velocity in tubes and the flow rate , the total flow area(A_f) calculated by:

$A_f = m_c / \rho * V$ (7.7)

Where:

m_c =0.14Kg/s

ρ= 1032.441Kg/m^3

V=0.26 m/s (velocity in tube)

Then:

$A_f = 5.2*10^{-4}$ m^2

This area is product of the number of tubes and the flow area per tube:

$A_f = n * \pi d^2/4$ (7.8)

Where:

n : is the number of tubes.

d : is the diameter of the selected tube

From the standard the project select atube with (0.2 inch) = $5.08*10^{-3}$m

Then:

$n= A_f*4 / \pi d^2$

= 25.6 = 26 tubes

The length of the tube (L) can be calculated by :

Area of heat transfer = number of tube* area of heat transfer of one tube

$A= n *(\pi d L)$ (7.9)

Where:

$A=0.50m^2$

$d=2.54*10^{-3}m$

$n=26$ tubes

Then:

$L=A/n \pi d$

$L= 1.20$ m

Then the total length of tubes obtained by:

Total length $= n* L =26*1.2 = 31.2$ m

The head loss through the heat exchanger is equivalent to head losses through a pipe has a follow:

$D=5.08*10^{-3}m$,

$V=0.26m$,

$L=31.2m$,

$f=0.044$

Then:

$$h_f = f\,(L/D)*\,(V^2/2g)$$

$$= 0.93\ \text{m}$$

7.2.7 Overall head losses through the first subsystem

The overall head losses through the cycle listed in table shown:

Table 7.6 The Overall Head Losses Through The Cycle

Element	Head losses (m)
Strainer	0.0006
Pretreatment filter	2.6
Membrane	688
Heat Exchanger	0.93
pipes	0.276
fittings	0.0272
	Σh_f=692

There is a static head(ΔZ) between the cycle inlet (strainer) and the cycle outlet (membrane outlet) which equal to (5 m).

Operating pressure produced by pump is adjusted to overcome the adverse effects of the following:

Overall Head losses (h_f total)

Static head (ΔZ)

Then the selected pumps must cover a head (697m).

7.2.8 Pumps in First Subsystem

The pump is used in desalination system to circulate the water in the system. The energy transferred from the pump to the fluid appears as kinetic and potential energy, so the primary purpose of a pump is to raise the energy of a fluid.

In this project the most suitable pump is a centrifugal pump since its characteristic satisfy the demand of the desalination system, because this pump provides handle high flow rates, smooth, no pulsating delivery, and regulates the flow rate over a wide range without damaging the pump. And have few moving parts, and the wear caused by normal operation is minimal. They are also compact and easily disassembled for maintenance.

This project use four pump in series in the first subsystem :

Here in this project a water tank used between tow pumps group (A,B), and (C,D), to separate the head that most each group must cover it.

Pump (A,B) operate at the following conditions :

- At Head equal to 351.84 / 2= 175.9 m.
- At flow rate equal to a feed flow rate ($1.81*10^{-4}$ m^3/s).

Table 7.7 The Total Head For The Pumps (A, B)

Element	Head losses (m)
Strainer	0.0006
Pretreatment filter	2.6
Membrane	688/2
Pipes(1-7)	0.225
Fittings(I,II)	0.024
	Σh_f=346.84

There is a static head (ΔZ) between the cycle inlet (strainer) and the cycle outlet (membrane outlet) which equal to (5 m).

So the overall head losses is equal to 346.84 + 5 = 351.84 m.

Then :

The hydraulic power for each pump (A,B) is calculated as:

$P = \rho\, g\, H\, Q$

$=1032.441*9.81*351.84\ /2*1.81*10^{-4}$

$=322.46$ watt, for each pump (A,B).

By using the following characteristic curve (figure 7.9) shown.

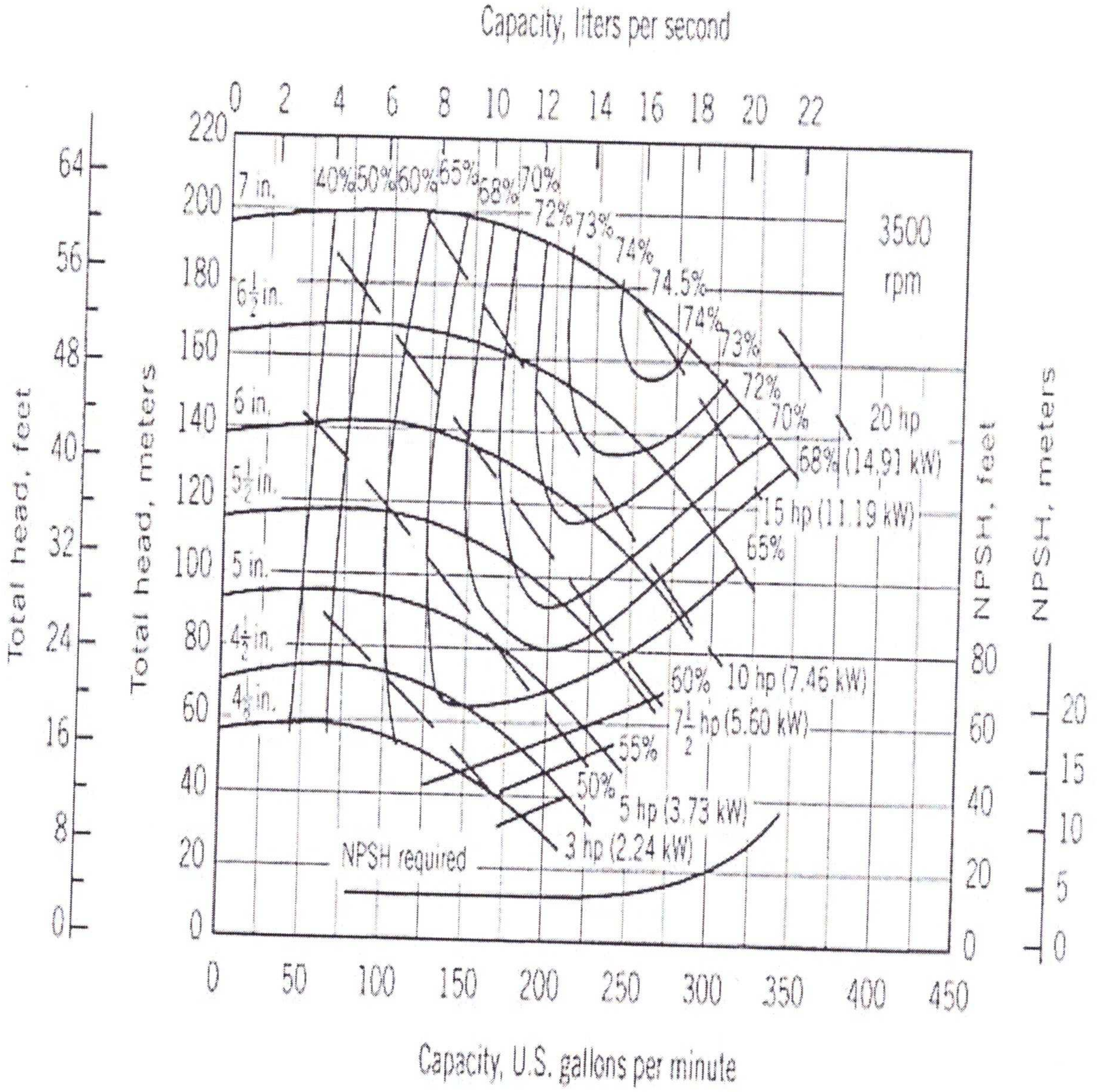


Figure 7.9 . Characteristic Curve for each pump (A, B).

Then the best selected pumps with the following specification

Table 7.8 Specifications of The Selected Pumps (A,B).

Number	Type	Head(m)	Pout(W)	Pin (hp)
Pump(A)	Centrifugal	175.9	322.46	5.5
Pump(B)	Centrifugal	175.9	322.46	5.5

Where:

Pin: Is the mechanical power from chart , (hp)

Pout: Is the hydraulic power (w).

pump (C,D) operate at the following conditions :

- At Head equal to 344.99/ 2= 172.5m.
- At flow rate equal to a feed flow rate ($1.35*10^{-4}$ m^3/s).

Table 7.9 The Total Head For The Pumps (C, D)

Element	Head losses (m)
Heat exchanger	0.93
Membrane	688/2
Pipes(8,9,10)	0.051
Fittings(III)	0.0032
	$\Sigma h_f=344.99$

So the total head is 344.99.

Then the hydraulic power for each pump (C,D) is calculated as:

$P = \rho g H Q$

$=1032.441*9.81*344.99/2*1.35*10^{-4}$

=235.86 watt for each pump (C,D).

By using the characteristic curve (figure 7.8), Then the best selected pumps with the following specification.

Table 7.10 Specification of The Selected Pumps(C,D)

Number	Type	Head(m)	Pout (W)	Pin (hp)
Pump(C)	Centrifugal	172.5	235.86	5
Pump(D)	Centrifugal	172.5	235.86	5

7.3 Calculations and Selections of The Second Subsystem Component.

7.3.1 Head losses In Pipes

Here in this project the pipe used in the second subsystem must be thermally isolated, the isolated material in this project Polystyrene-Exp'd which has a thermal conductivity (k) equal to 0.03, see appendix A (A-4), and the required thickness of the isolated material obtained from appendix A(A-4), which nearly equal to (27mm) at the selected pipe diameter and maximum water temperature 100 c°, (from roymech company)

Table 7.11 Loses Through Second Subsystem Pipe

Pipe #	Type	ε (mm)	D (m)	ε/D	L (m)	V (m/s)	Q (m^3/s)	Re	f	h_f (m)
11	Cast Iron	0.203	0.0254	0.008	2	0.69	$3.5*10^{-4}$	17526	0.039	0.07
12	Cast Iron	0.203	0.0254	0.008	2	0.69	$3.5*10^{-4}$	17526	0.039	0.07
13	Cast Iron	0.203	0.0254	0.008	2	0.69	$3.5*10^{-4}$	17526	0.039	0.07
14	Cast Iron	0.203	0.0254	0.008	2	0.69	$3.5*10^{-4}$	17526	0.039	0.07
15	Cast Iron	0.203	0.0254	0.008	1	0.69	$3.5*10^{-4}$	17526	0.039	0.037
16	Cast Iron	0.203	0.0254	0.008	1	0.73	$3.7*10^{-4}$	18542	0.037	0.039
17	Cast Iron	0.203	0.0254	0.008	1	0.73	$3.7*10^{-4}$	18542	0.037	0.039
18	Cast Iron	0.203	0.0254	0.008	2	0.73	$3.7*10^{-4}$	18542	0.037	0.079

In the table 7.14 the flow rate through the pipe as follow:

- Pipes (11,12,13,14,15) have a flow rate equal to the feed flow rate which equal to $3.5*10^{-4}$ m^3/s.
- Pipes (16,17,18) have a flow rate equal to $3.7*10^{-4}$ m^3/s , which is suitable for the selected evacuated tube area.

7.3.2 Head Losses in Fittings

Table 7.12 head losses in fittings.

Fittings #	Type	K	V (m/s)	Q (m^3/s)	h_f (m)
IV	Elbow90°	2	0.69	$3.5*10^{-4}$	0.048
V	Elbow90°	2	0.69	$3.5*10^{-4}$	0.048

7.3.3 Tank Design

The Tank is used to mixing hot water which comes from evacuated tube parts and cold water coming from the membrane parts. Keeps the temperatures of feed water to the membrane in the range (52-60C^{0}).The tank is isolated using polyurethane, stainless steel and galvanized steel isolation. The design is done using the following:

Calculate heat transfer equation through the tank cylinder wall:

$$Q = U \times \Delta T \qquad (7.10)$$

Where:

Q: Heat transfer load (W).

U: Overall heat transfer (W/m$^{2}C^{0}$).

ΔT: The temperatures difference(C^{0}).

$$U = 1/R_{th} \qquad (7.11)$$

Where

R_{th}=R convection +R conduction

$$R_{th} = \frac{1}{h_o 2\pi l r_o} + \frac{1}{2\pi l}\left[\frac{1}{k_p}\ln\frac{r_p}{r_i} + \frac{1}{k_s}\ln\frac{r_s}{r_p} + \frac{1}{k_G}\ln\frac{r_G}{r_s}\right] + \frac{1}{h_i 2\pi l r_i} \qquad (7.12)$$

Where

R_{th}: Overall thermal resistance (m^{2} C^{0}/w)

h_o: Convection heat transfer coefficient for air which is chosen equal 50 (W/ m$^{2}C^{0}$).

h_i: Convection heat transfer coefficient for hot water which is chosen equal 2000

$(W/m^2 C^0)$.

k_p: Thermal conductivity for polyurethane (W/mC^0).

k_s: Thermal conductivity for stainless steel (W/mC^0).

k_G: Thermal conductivity for galvanized steel (W/mC^0).

L: length of the tank, is chosen equal (1.5m)

r_i: Tank inner cross section radius taken as 0.18m

r_p: Polyurethane cross section radius taken as 0.235m

r_s: Stainless steel cross section radius taken as 0.260m

r_o: galvanized steel (r_G) or tank outer cross section radius taken as 0.2605m

Isolation consists of three layers fabricated from material shown in table (7.13) with their thicknesses and thermal conductivities.

Table 7.13 Isolation Layer with their thicknesses and thermal conductivities.

Isolation material	Thermal conductivity (W/mC^{0}) K	Thickness of layer(m)
Polyurethane	0.027	0.55
Stainless steel	15	0.25
Galvanized steel	40	0.0005

The calculation brought the tank specification shown in table (7.14)

Table 7.14 Tank Specification

tank specification	Brought values
Overall thermal resistance (R_{th})	1.084($m^2 C^0/w$)
Overall heat transfer (U)	0.922($W/m^2 C^0$).
Heat transfer load (Q).	7.38(W)
Diameter of the tank (di)	0.36(m)
Length of the tank (L)	1.5(m)
Standard volume (v)	500(L)

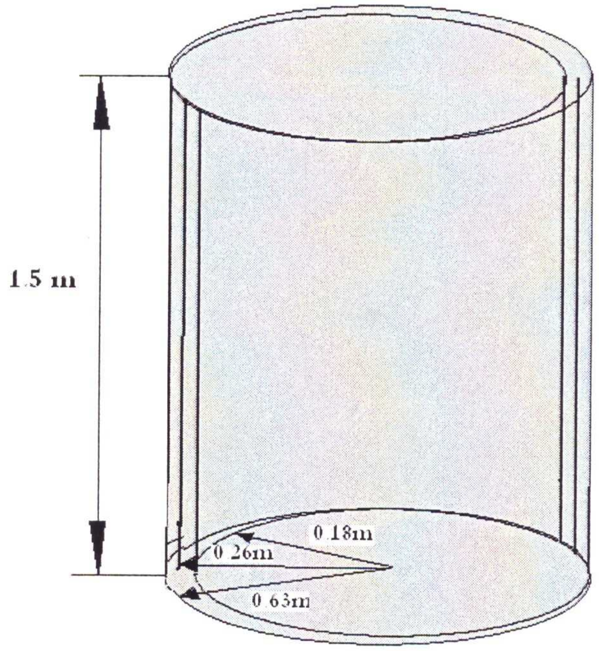


Figure 7.10 Hot Water Tank

7.3.4 Evacuated Tube

7.3.4.1 Collector Performance

The efficiency of a solar collector is defined as the quotient of usable thermal energy versus received solar energy. Besides thermal loss there always is optical loss as well. The conversion factor or optical efficiency h0 indicates the percentage of the solar rays penetrating the transparent cover of the collector (transmission) and the percentage being absorbed.

Basically, it is the product of the rate of transmission of the cover and the absorption rate of the absorber.

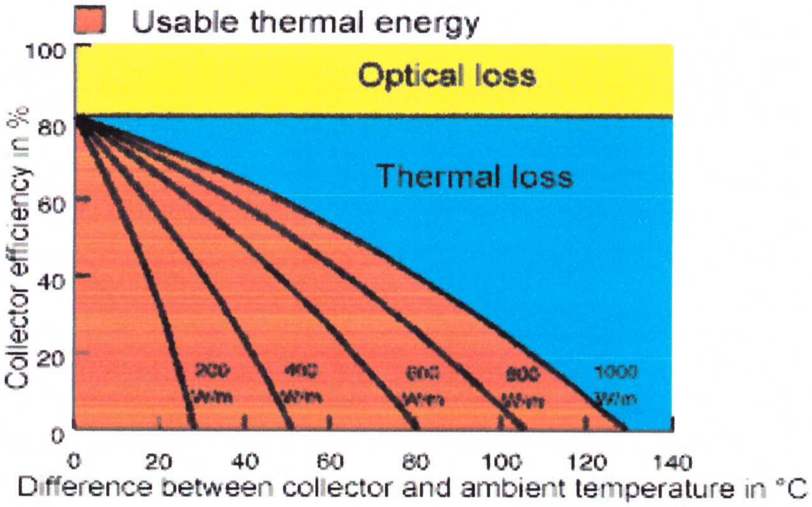


Figure 7.11 Efficiency Graph of Solar Collector Performance

The heat loss is indicated by the thermal loss factor. This is given in watt per m^2 collector surface and the particular temperature difference (in °C) between the absorber and its surroundings. The higher the temperature difference, the more heat is lost. Above a specific temperature difference, the amount of heat loss equals the energy yield of the collector, so that no energy at all is delivered to the solar circulation system. A good collector will have a high conversion factor and a low thermal loss factor

Table 7.15 Collector Characteristics

Type of collector	Conversion factor	Thermal loss factor (W/m^2 °C)	Temp. range (°C)
uncovered absorber	0.82 - 0.97	10 - 30	up to 40
flat-plate	0.66 - 0.83	2.9 - 5.3	20 - 80
evacuated-plate	0.81 - 0.83	2.6 - 4.3	20 -120
evacuated-tube	0.62 - 0.84	0.7 - 2.0	50 - 120
reservoir collector	about 0.55	about 2.4	20 - 70
air collector	0.75 - 0.90	8 - 30	20 - 50

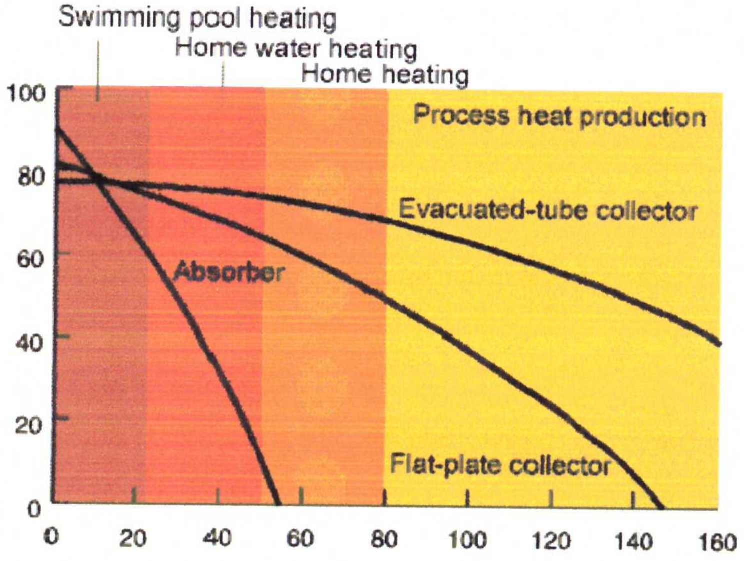


Figure7.12 Efficiency and Temperature Range of Various Types of Collector (Radiation: 1000 W/m^2)

7.3.4.2 Collector Specifications

In this project the types of collectors will be investigated evacuated tube collector. This types of collector are available in Palestine markets, so project selection is AL-Sun solar water heating for evacuated tube collector has a code (EN12975).

Table 7.16 Evacuated Tube Basic Specifications

Length (nominal)	1500mm /1800mm
tube diameter	58mm
Thermal expansion	3.3x10-6 C^{o}
Material	Borosilicate Glass 3.3
Vacuum	P<5x10-3 Pa
Heat Loss	<0.8W/ ($m^{2}C^{o}$)
Maximum Strength	0.8MPa
The distance between the tubes	20mm

7.3.4.3 Evacuated tube collector design

Table7.17 Design Calculation for Evacuated Tube.

Specific Nominal Capacity [W/m^2]	631
Effective collector area [m^2]	18.5
The number of tubes	178
Mass flow rate per unit area [kg/s. m^2]	0.02
Total flow rate [kg/s]	0.37
Area of collector [m^2]	25

To find the area of collector, and the number of tubes :

From energy balance on heat exchanger where the first subsystem needs to be a quantity of heat (11710 W)

Also for testing of Sun solar water heating for evacuated tube collector, The specific nominal capacity per area(P_a) of the collector is defined as :

$P_a = G*\eta_o - a_1*(Tm-Ta) - a_2*(Tm-Ta)^2$ (7.13)

Where:

η_o = Zero Loss Efficiency

a_1 = First order heat loss coefficient ($W/m^2.K$)

a_2 = Second order heat loss coefficient ($W/m^2.K^2$)

G =Solar radiation falling into the collector per unit area

Tm= mean collector temperature =(T water out of collector +T water in collector)/2

Ta= ambient temperature.

The average values for parameter η_o, a_1, a_2 were sourced from a study done by the European Solar Thermal Industry Federation (ESTIF) that tested collectors in Europe. The values are given from AL-Sun solar water heating for Evacuated Tube Collectors test :

Table7.18 Values of AL-Sun Solar Water Heating for Evacuated Tube Collectors Test

η_o	0.76
a_1	1.2 $W/m^2.K$
a_2	0.008 $W/m^2.K^2$
Tm	56 C°
Ta	20 C°
G	900 w/m^2 , in August month

The solar irradiance (G) will be take in this project in August month in Jerusalem city (from f-chart program which equal to 25920 KJ/m^2 , and G is a function of time irradiance that equals in this project (8 hr), also G = 25920 *1000/(8*3600) = 900 w/m^2

Then:

$$P_a = 900 * 0.76\text{-}1.2*(56\text{-}20)\text{-}0.008*(56\text{-}20)^2 = 631\ W/m^2$$

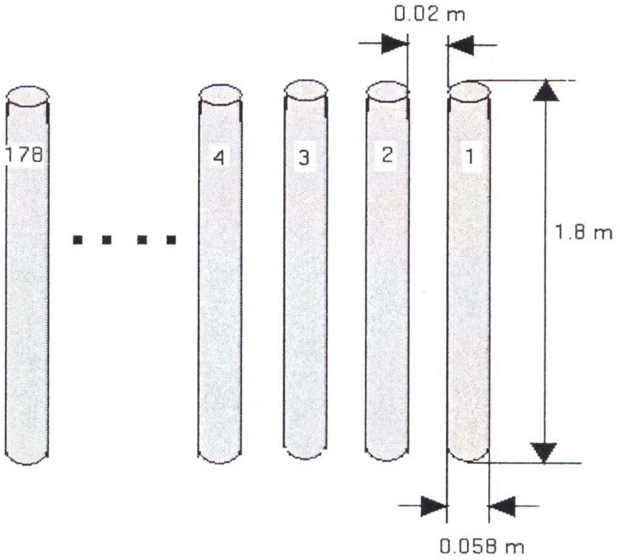


Figure7.13 Evacuated Tubes Dimension

Then :

A_{eff} = quantity of heat /P_a (7.14)

Where :

$A_{eff:}$ The effective collector area

= 11710/ 631= 18.5 m^2

, So

$A_{eff} = n*L*d$ (7.15)

Where:

n: The number of tubes

L: length of collector

d: diameter of collector

Then :

The number of tube =18.5/(1.8*0.058)= 178 tube

The mass flow rate per unit area= 0.02 kg/s. m^2

Then the total flow rate for evacuated tube = 0.02* A_{eff}

= 0.02 * 18.5=0.37 kg/s

Then

The total volume flow rate(Qc) = 0.37/1000= $3.7*10^{-4}$ m^3/s

Area of collector (A) = $[(A_{eff}) + (B * n * L)]$ (7.16)

Where:

B: the distance between tube

Then

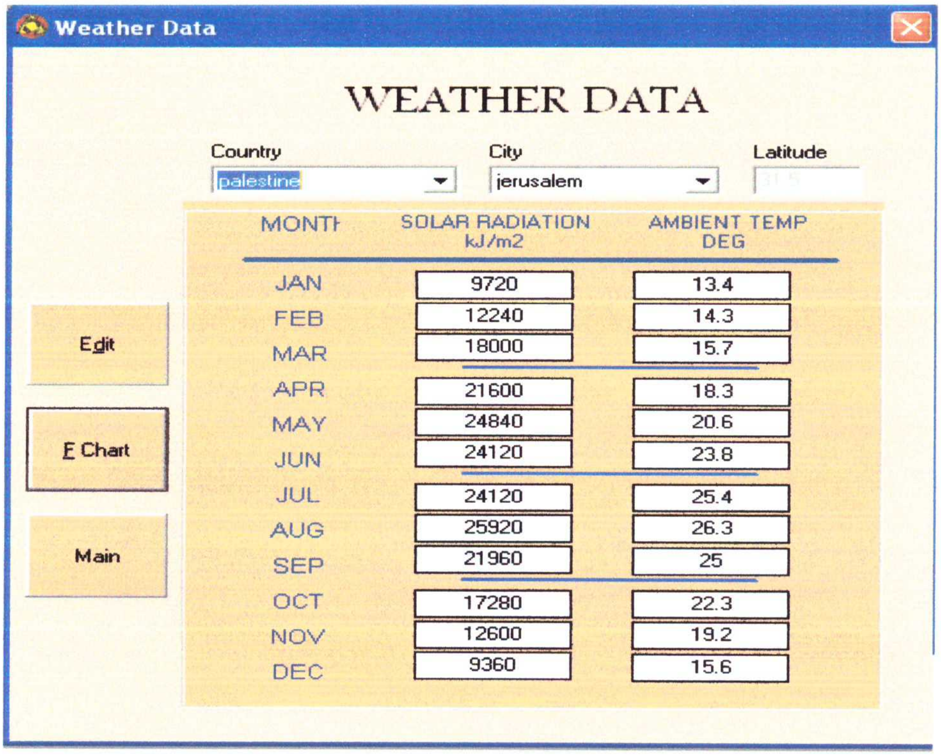
$$A= [(18.5) + (0.02*178*1.8)] = 25\ m^2$$

7.3.4.4 F-Chart Program

F-Chart is a program that is developed by (National Energy Research Center, Solar Water Heater, Jordan, 2003)

The energy supplied by the collector to the total consumed load called the F-factor and equal to zero (when total consumed load covered by the auxiliary heating), and one (when total load covered by solar collectors).

The F-Chart program provides a weather data for any country, so select a country from the country field and select a city from city field fig (7.15). Then select a collector type from a collector type field. And finally fill the data input field fig (7.16) which are:



WEATHER DATA

Country: palestine
City: jerusalem
Latitude: 31.5

MONTH	SOLAR RADIATION kJ/m2	AMBIENT TEMP DEG
JAN	9720	13.4
FEB	12240	14.3
MAR	18000	15.7
APR	21600	18.3
MAY	24840	20.6
JUN	24120	23.8
JUL	24120	25.4
AUG	25920	26.3
SEP	21960	25
OCT	17280	22.3
NOV	12600	19.2
DEC	9360	15.6

Figure 7.14 Weather data window

Area: solar collector area, (m^2).

Tank area: storage tank surface area, (m^2).

U tank: storage tank heat transfer coefficient, (W/m^2).

HX eff: heat exchanger efficiency.

$\tau\alpha$ Efficiency: average $\tau\alpha$ to normal $\tau\alpha$ when solar radiation is perpendicular to collector surface (recommended value 0.96).

Two: required collector's outlet water temperature, (C°).

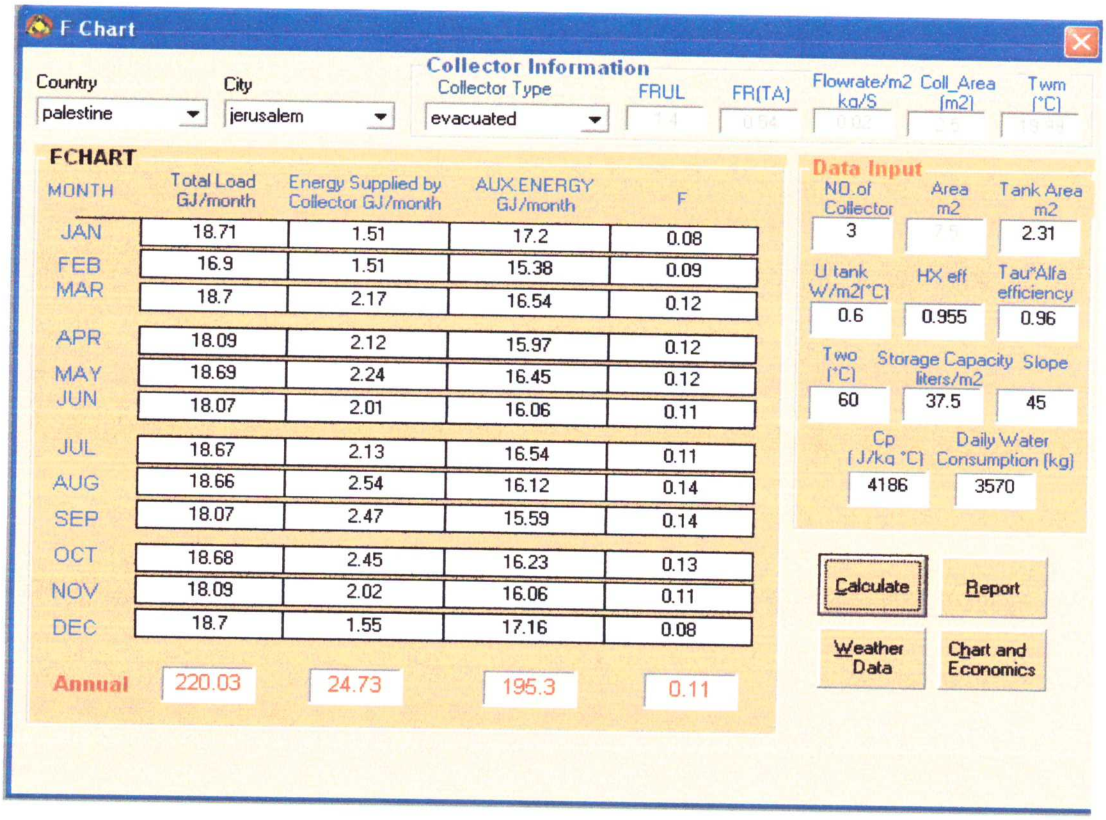
Storage capacity: amount of water to be stored for each square meter of collectors area, (litters/m²).

Slope: collectors slope, (degrees).

C_P : Specific heat capacity of the fluid to be heated (4186 J/kg.C°. for water),

Daily water consumption: quantity of required hot water, (kg/day).

Upon filling the required data, press on the press calculate in order to obtain the F-Chart results



Country: palestine
City: jerusalem

Collector Information

Collector Type	FRUL	FR(TA)	Flowrate/m2 kg/S	Coll_Area (m2)	Twm (°C)
evacuated	1.4	0.54	0.02	2.5	19.99

FCHART

MONTH	Total Load GJ/month	Energy Supplied by Collector GJ/month	AUX.ENERGY GJ/month	F
JAN	18.71	1.51	17.2	0.08
FEB	16.9	1.51	15.38	0.09
MAR	18.7	2.17	16.54	0.12
APR	18.09	2.12	15.97	0.12
MAY	18.69	2.24	16.45	0.12
JUN	18.07	2.01	16.06	0.11
JUL	18.67	2.13	16.54	0.11
AUG	18.66	2.54	16.12	0.14
SEP	18.07	2.47	15.59	0.14
OCT	18.68	2.45	16.23	0.13
NOV	18.09	2.02	16.06	0.11
DEC	18.7	1.55	17.16	0.08
Annual	220.03	24.73	195.3	0.11

Data Input

NO.of Collector: 3
Area m2: 7.5
Tank Area m2: 2.31
U tank W/m2(°C): 0.6
HX eff: 0.955
Tau*Alfa efficiency: 0.96
Two (°C): 60
Storage Capacity liters/m2: 37.5
Slope: 45
Cp (J/kg °C): 4186
Daily Water Consumption (kg): 3570

Figure 7.15 Calculation Window

Evacuated tube collector which has these properties ($F_R U_L$ =1.4,$F_R \tau\alpha$=0.54, mass flow rate=0.02 kg/s.m^2 ,collector area =25m^2,water main temperature =20$^\circ C$).after that fill these input data in f-chart program and click calculate to show output data.

7.3.4.5 F-chart calculation for evacuated tube collector

Table 7.19 Evacuated Tube Calculations

Area(m^2)	F-Factor	Energy(collector)
12.5	0.1	41.18
25	0.2	79.22
37.5	0.28	114.35
50	0.36	146.79
62.5	0.44	176.72
75	0.51	204.33
87.5	0.57	229.79
100	0.63	253.25
112.5	0.68	274.86

125	0.73	294.76
137.5	0.77	313.07
150	0.82	329.92
162.5	0.85	345.39
175	0.88	357.84
187.5	0.91	367.73
200	0.93	376.68
212.5	0.95	383.53
225	0.96	387.14
237.5	**0.96**	**389.49**

7.3.4.6 F-chart results for evacuated tube collector

1) Energy curves.

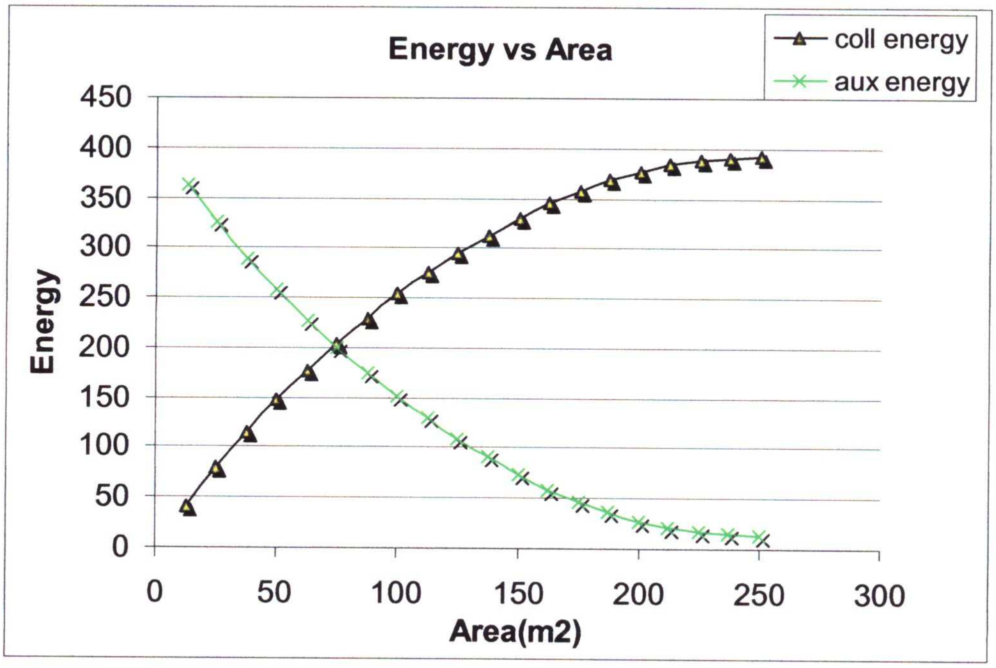


Figure 7.16 Energy vs. Area

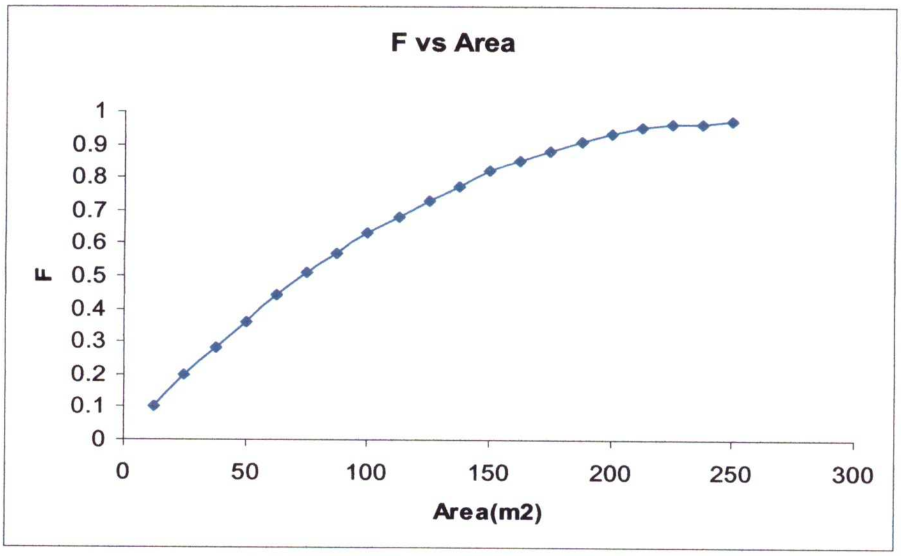


Figure 7.17 F vs Area

2) Cost Curve

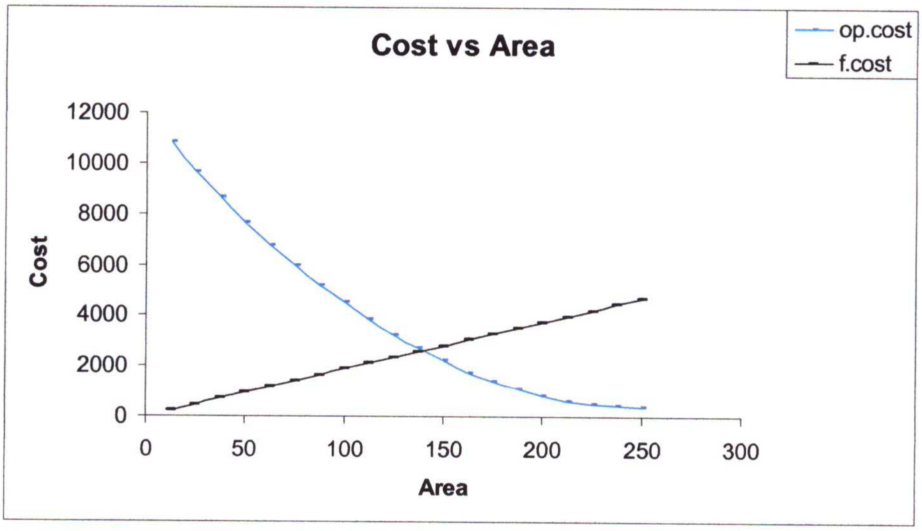


Figure 7.18 Operation Cost vs. Area

7.3.5 Pumps in Second Subsystem

This project use two pump in the second subsystem :

Pump (E) operate at the following conditions :

- At Head equal to 3.343m.
- At flow rate equal to a feed flow rate ($3.5*10^{-4}m^3/s$).

Table 7.20 The Total Head For Pump (E)

Element	Head losses (m)
Pipes (11-15)	0.317
Fitting (IV, V)	0.096
Heat exchanger	0.93
	$\Sigma h_f=1.343$

There is a static head (ΔZ) between (hot water tank outlet) and (hot water tank inlet) which equal to (2 m).

So the total head is 1.343+2 =3.343m

Then the hydraulic power for each pump (E) is calculated as:

$P = \rho \, g \, H \, Q$

$= 1000 * 9.81 * 3.343 * 3.5 * 10^{-4}$

= 11.47 watt, for pump (E).

By using the following characteristic curve (figure 7.19) shown.

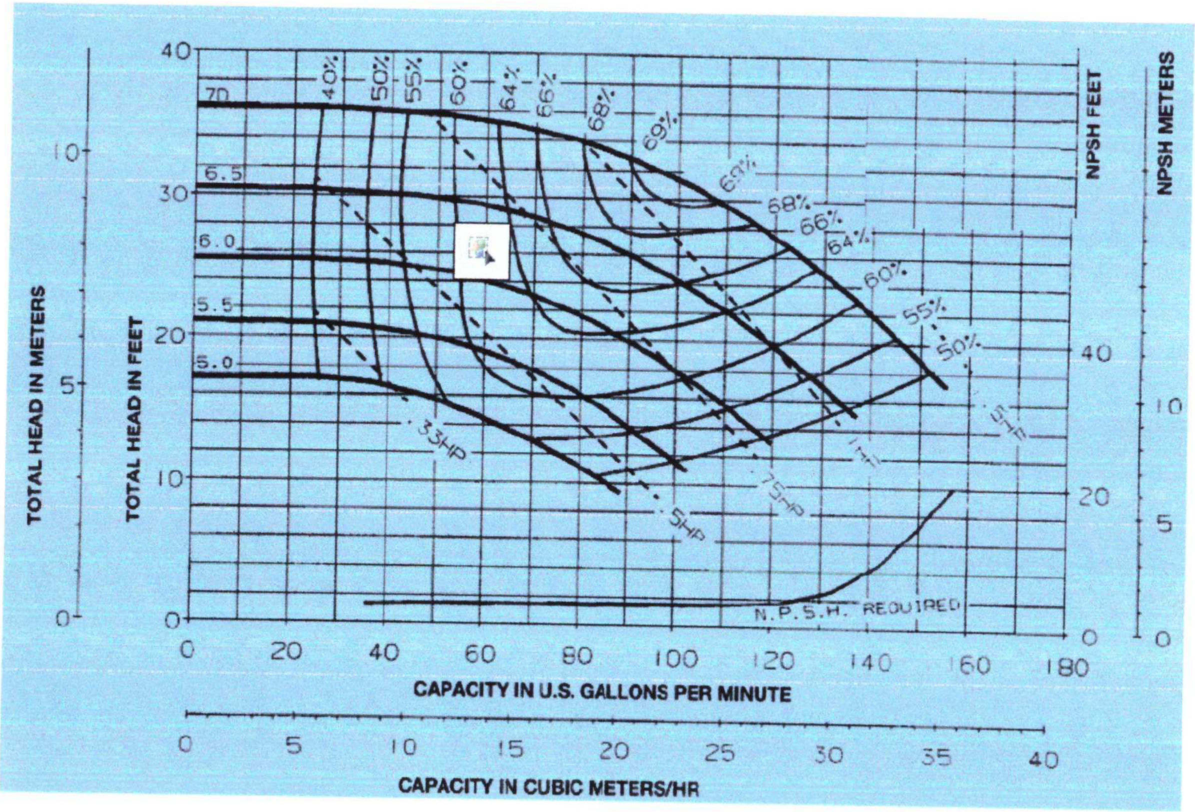


Figure 7.19 Characteristic Curve for pump (E).

Then the best selectedpumps with the following specification

Table 7.21 Specification of The Selected Pump (E)

Number	Type	Head	Pout(W)	Pin (hp)
Pump(E)	centrifugal	1.343	11.47	0.2

Pump (F) operate at the following conditions :

- At Head equal to 2.317m.
- At flow rate equal to a feed flow rate ($3.7*10^{-4}m^3/s$).

Table 7.22 The Total Head For Pump (E)

Element	Head losses (m)
Pipes (16,17,18)	0.317
Evacuated Tube	0 (roughness=0)
	Σh_f=0.317

There is a static head (ΔZ) between (hot water tank outlets) and (hot water tank inlet) which equal to (2 m).

So the total head is 0.317+2 =2.317m

Then the hydraulic power for each pump (E) is calculated as:

$P = \rho g H Q$

$=1000*9.81*2.317*3.7*10^{-4}$

= 8.41 watt, for pump (F).

By using the characteristic curve (figure 7.19), Then the best selected pumps with the following specification

Table 7.23 Specification of The Selected Pump (F)

Number	Type	Head	Pout(W)	Pin(hp)
Pump(F)	centrifugal	2.317	8.41	0.15

7.4 Component and Selection of the Third Subsystem

7.4.1 Selection of Photovoltaic Cells:

There are two type of solar system which each one have its components and they are:

1. **Off-Grid Solar System**

There are many components that make up a complete solar system, but the 4 main items on a stand-alone system are: solar modules, charge controller(s), battery(s) and inverter(s) shown in fig (7.20).The solar modules are physically mounted on a mount structure and the DC power they produce is wired through a charge controller before it goes on to the battery bank where it is stored. The two main functions of a charge controller are to prevent the battery from being overcharged and eliminate any reverse current flow from the batteries back to the solar modules at night. The battery bank stores the energy produced by the solar array during the day for use at anytime of the day or night. Batteries come in many sizes and grades. The inverter takes the DC energy stored in the battery bank and inverts it to 120 or 240 VAC to run your AC appliances.

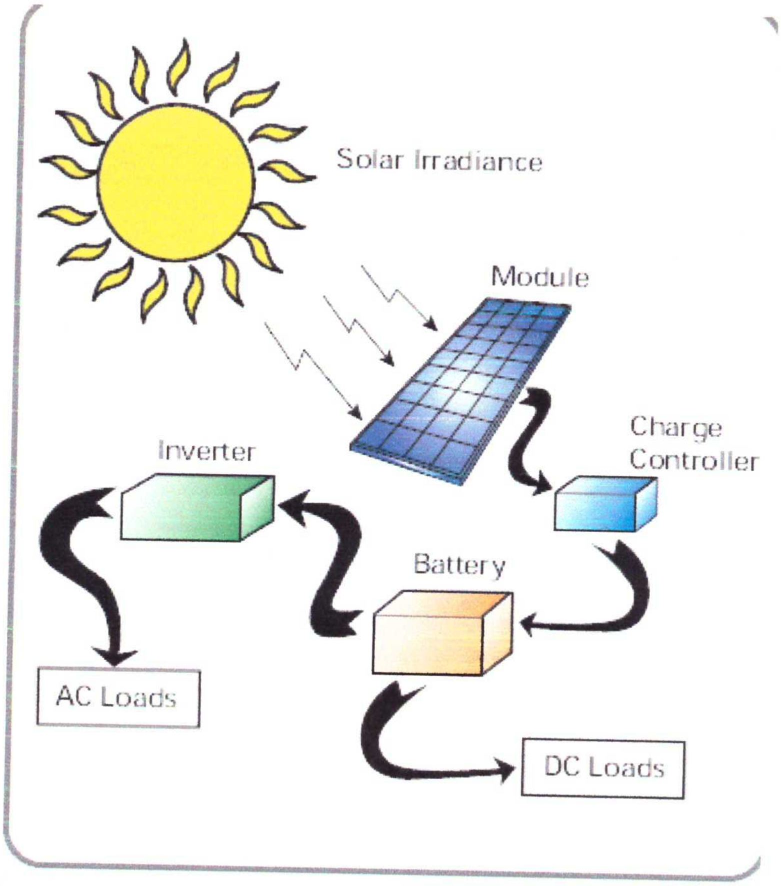


Figure 7.20 Components of Off-Grid Solar System

2. Grid-Tie System

Grid-tie systems are inherently simpler than either grid-tie with battery back-up or stand-alone solar systems. In fact, other than safety disconnects, mounting structure and wiring, a grid-tie system is just solar modules and a grid-tie inverter! Today's sophisticated grid-tie inverters incorporate most of the components needed to convert the direct current from the modules to alternating current, track the maximum power point of the modules to operate the system at peak efficiencies and terminate the grid connection if grid power is interrupted from the utility.

In this project the grid-tie system will be used.

7.4.2 Grid-Tie System Components:

A. Solar Module Selection

Solar module selection depends on the number of the panel that used in this project and there are one way used to calculating the number of solar panel which is:

- **Hydraulic Power of The Pumps**

  In this method the hydraulic power of the pumps chosen are used to fined the required number of the solar module.

  To fined the number of solar module these steps must been followed:

I. Calculate of power input:

$$P_{in} = P_h/\eta \qquad (7.17)$$

Where:

P_{in}: Input power of the pumps (KW)

P_h: Hydraulic power of the pumps (KW)

η : Efficiency of the pumps which is chosen equal 0.85.

II. Calculate of solar power

$$P_s = P_{in}/\eta \tag{7.18}$$

Where:

P_s: Solar power (KW)

P_{in}= Input power of the pumps (KW)

η= Efficiency of the inverter which is chosen equal 0.91.

By finding the P_s type of solar module will be selected from catalog see appendix A (A-5).

III. Calculate number of solar module (N.O.S.M)

$$N.O.S.M = P_s / P_m. \tag{7.19}$$

Where:

N.O.S.M: Number of solar module

P_s: Solar power (KW)

P_m= Power for the single module from selected type (KW).

The numbers of module selected are connected in series to give the required power.

The calculation brought the module selection shown in table (7.27)

Table 7.24 Module Selection.

Module specification	Brought values
Total Hydraulic power of the pumps (P_h)	1.496(KW)
Input power of the pumps (P_{in})	1.337(KW)
Solar power (P_s)	1.496(KW)
Type of module selected	KC200GT
Selected module power(P_m)	0.2(KW)
Number of solar module (N.O.S.M)	7 Module
Solar module price	750$
Total solar module price	5250$

B. Inverter Selection

The inverter is a basic component of PV systems and it converts DC power from the batteries or in the case of grid-tie, directly from the PV array into high voltage AC power as needed. Inverters of the past were inefficient and unreliable while today's generation of inverters are very efficient (85 to 94%) and reliable.

Two types of stand-alone inverters predominate the market – modified sine and sine wave inverters. Modified sine wave units are less expensive per watt of power and do a good job of operating all but the most delicate appliances. Sine wave units produce power which is almost identical to the utility grid, will operate any appliance within their power range, and cost more per watt of output.

Utility-tie systems / sine wave inverters for utility interactive photovoltaic applications, provide direct conversion of solar electric energy to utility power with or without a battery storage system. These systems are designed to meet or exceed utility power company requirements and can be paralleled for any power level requirement.

To select the inverter, the power which enter to it must be calculated and then select the inverter from the catalog see appendix A (A-6).

$$P_0 = P_s \times \eta_i \qquad (7.20)$$

Where:

P_o: Output power of inverter (KW)

P_s: Solar power (KW)

η_i: Efficiency of inverter.

The calculation brought the inverter selection shown in table (7.28)

Table 7.25 Inverter Selection.

Inverter specifications	Brought value
Solar power (P_s)	1.496(KW)
Input power of inverter (P_i)	1.361(KW)
DC Input voltage (VDC)	183(V)
Type of inverter selected	Sunny Boy Inverter 1800U SBD with LCD
Inverter price	2550$

C. System Cables Interconnects Selection

Cables are very important for the system since it protect it from power lost and from compliant water-tight connections. There are two types of the cables interconnect:

- **Module Interconnects and Panel Output Cables**:

Proper connection of project solar modules to each other and to other components is crucial to the overall performance of project photovoltaic system. Without proper wiring, power from project solar array may be lost right at the source before it ever gets to project inverter. The module interconnects and panel output cables make it very easy to make clean, code-compliant, water-tight connections.

By depending on the output direct current (DC) from selected module the diameter of the cable and the maximum length will be known .

- **Inverter Interconnects Cables**

By depending on the input direct current (DC) from selected inverter the thickness of the cable and the maximum length will be known, see in appendix A (A-7).

The value of selection cables for the solar module and inverter shown in table (7.29).

Table 7.26 Selection Cables for the Solar Module and Inverter.

Parameter	Solar module	Inverter
Current	7.6(A)	12(A)
thickness	1.5(mm)	1.5(mm)
Maximum length	70(m)	50(m)

7.5 Software Programming Simulation

This project use a software programming to simplify a hole system calculations by using "MATLAB" program by making the following block diagram shown in the figure (7.21):

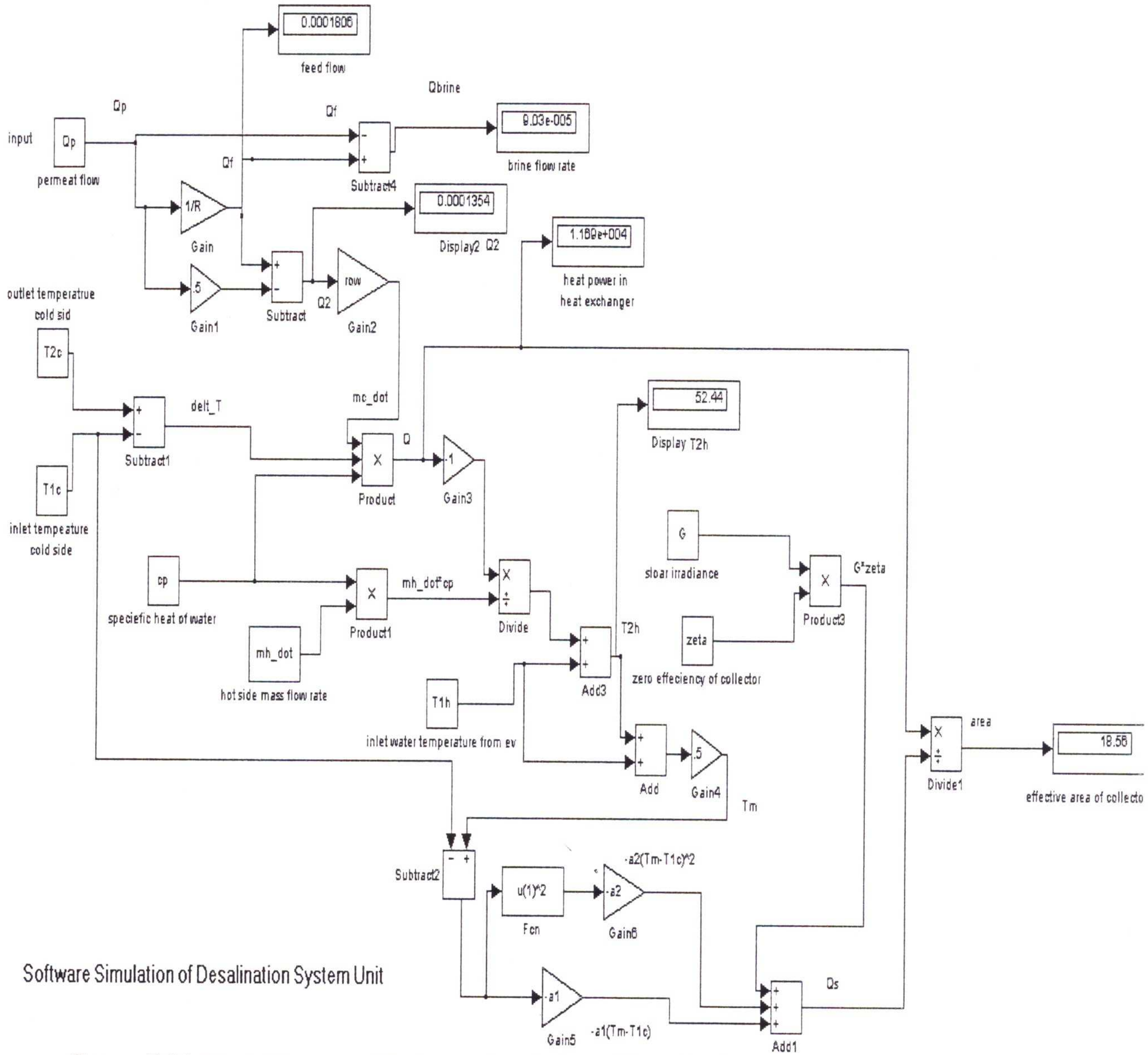


figure 7.21 Block Diagram of Software Simulation of Desalination System Unit.

The following function represent the body of used program :

```
function
[Q,Q2,Qf,Qbrine,T2h,area]=ahmad(Qp,R,T1c,T2c,T1h,mh_dot,G)
%Parameters
row=1033;
zeta=.76;
cp=4182;
a1=1.2; % first order heat loss
a2=.008;% second order heat loss
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%Qf=Qp/R;
Q2=Qf-0.5*Qp;
mc_dot=Q2*row;
delt_T=T2c-T1c;
Q=mc_dot*cp*delt_T;
T2h=-(Q/(mh_dot*cp))+T1h;
Tm=(T1h+T2h)/2;
Qs=G*zeta-a1*(Tm-T1c)-a2*(Tm-T1c)^2;  %specific nominal
heat capacity
```

```
area=Q/Qs;  %%effective area of evacuated tube
Qbrine=Qf-Qp;
plot(Qf,Qp)
```

Chapter Eight 8

Recommendations and Conclusions

Contents:

8.1 Recommendations

This project recommended to people whom will use desalination system several important notes:

- ✓ This project occur in bad conditions if use sea water as a feed water, but if use the brackish water the efficiency will increase.
- ✓ The membrane module has a high resistance against the flow, the resistance depends on the membrane geometry and concentration of the salt water.
- ✓ The used pumps mustn't have a higher pressure than the required pressure, because this will damage membrane.
- ✓ The desalination system unit generally has a higher efficiency in summer season.

8.2 Conclusions

- ✓ A desalination system is an idea created and improved to facing the water shortness .

- ✓ The desalination system unit used in this project required a specified condition to work at acceptable efficiency like average radiation sun rate must relatively high.

- ✓ Like this project can be improved and becomes bigger with larger benefits by corporate with ministry of water.

- ✓ This project has an advantage represented in using a renewable energy, which keep environment more healthy.

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APPENDIX

A

(A-1)

Hydraulic Roughness for Several Pipes Material

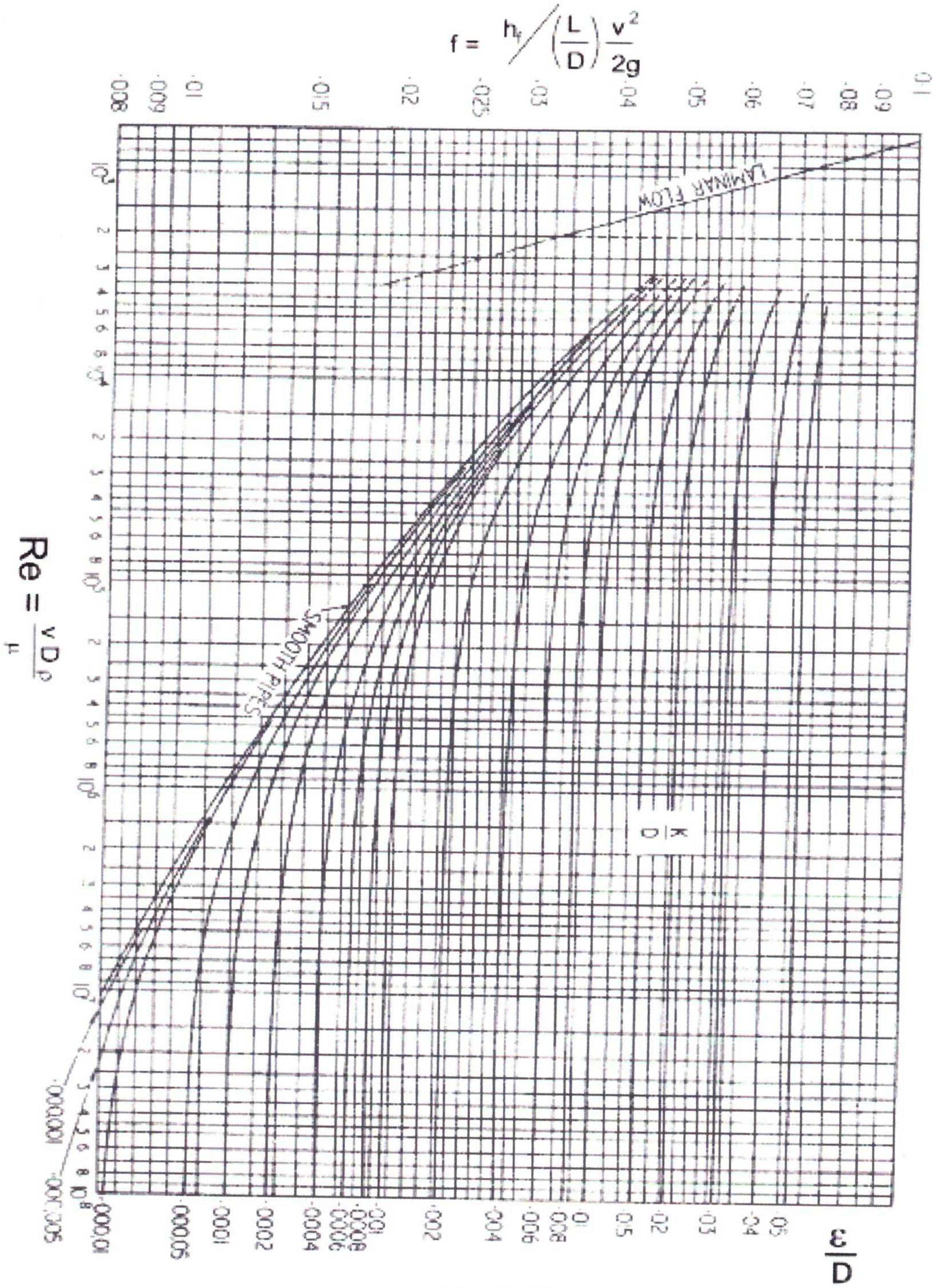
Type of Pipe	$\epsilon .10^3..(= \epsilon_{mm})$
Cast Iron	0.203
Galvanized Steel	0
Steel/Wrought Iron	0.051
Riveted Steel	0.91 – 9.1
Asphalted Cast Iron	0.12
Wood-Stave	0.18 – 0.91
Concrete	3.0
Spun Concrete	0.203
Drawn Copper, Brass Steel, Glass	Smooth

(A-2)

Physical Properties of Water

Temperature	Density	Specific weight	Dynamic viscosity	Kinematic viscosity	Vapor pressure
	kg/m³	N/m³	N · s/m²	m²/s	N/m² abs.
0°C	1000	9810	1.79×10^{-3}	1.79×10^{-6}	611
5°C	1000	9810	1.51×10^{-3}	1.51×10^{-6}	872
10°C	1000	9810	1.31×10^{-3}	1.31×10^{-6}	1230
15°C	999	9800	1.14×10^{-3}	1.14×10^{-6}	1700
20°C	998	9790	1.00×10^{-3}	1.00×10^{-6}	2340
25°C	997	9781	8.91×10^{-4}	8.94×10^{-7}	3170
30°C	996	9771	7.97×10^{-4}	8.00×10^{-7}	4250
35°C	994	9751	7.20×10^{-4}	7.24×10^{-7}	5630
40°C	992	9732	6.53×10^{-4}	6.58×10^{-7}	7380
50°C	988	9693	5.47×10^{-4}	5.53×10^{-7}	12,300
60°C	983	9643	4.66×10^{-4}	4.74×10^{-7}	20,000
70°C	978	9594	4.04×10^{-4}	4.13×10^{-7}	31,200
80°C	972	9535	3.54×10^{-4}	3.64×10^{-7}	47,400
90°C	965	9467	3.15×10^{-4}	3.26×10^{-7}	70,100
100°C	958	9398	2.82×10^{-4}	2.94×10^{-7}	101,300

(A-3)



Moody Chart

(A-4)

	Pipe contents temperature = 100 Deg.C					
Pipe OD	Insulation Thickness (mm)					Heat Loss
	k=0,02	k=0,03	k=0,04	k=0,05	k=0,06	(W/m)
17,2	11	22	40	72	125	10,4
21,3	12	24	44	76	128	11,1
26,9	14	27	47	78	128	12,1
33,7	15	29	50	80	128	13,2
42,4	17	32	53	83	128	14,5
48,3	18	33	55	85	129	15,3
60,3	20	36	58	88	130	16,8
76,1	23	39	62	92	131	18,7
88,9	24	42	65	94	133	20,1
101,6	26	45	67	96	134	21,5
114,3	27	48	69	98	136	22,8
139,7	29	49	72	101	137	25,4
168,3	31	52	77	107	143	27,8
219,1	34	56	81	110	145	32,5
244,5	35	57	82	112	146	34,8
273,0	37	59	85	114	149	37,1
323,9	38	61	87	117	150	41,5
355,6	39	62	89	118	151	44,2
406,4	41	65	91	121	153	48,2
457,0	42	66	92	122	154	52,5
508,0	43	68	95	124	157	56,2
610 +	49	77	107	141	177	59,4

Insulation	k (λ) =$Wm^{-1}K^{-1}$
Balsa	0,048
Cotton Wool	0,029
Felt	0.04
Glass Wool (20° C)	0,04
Magnesia	0,07
Rock Wool	0,045
Slag Wool	0,042
Sheeps Wool	0,038
Expanded Perlite	0,035 to 0,06
Calcium silicate	0.054-0.068 (100°C.)
Cellular Glass	0.043-0.055

Insulation	k (λ) =$Wm^{-1}K^{-1}$
Straw-Comp	0,09
Polystyrene-Exp'd	0,03
Kapok	0,034
Glass Wool (100°C)	0,07
Plywood	0,13
Sawdust	0,06
Wood	0,13
Cellulose	0,039
Polyisocyanurate foam	0,023
Exfoliated vermiculite	0.062
Magnesia	0.058

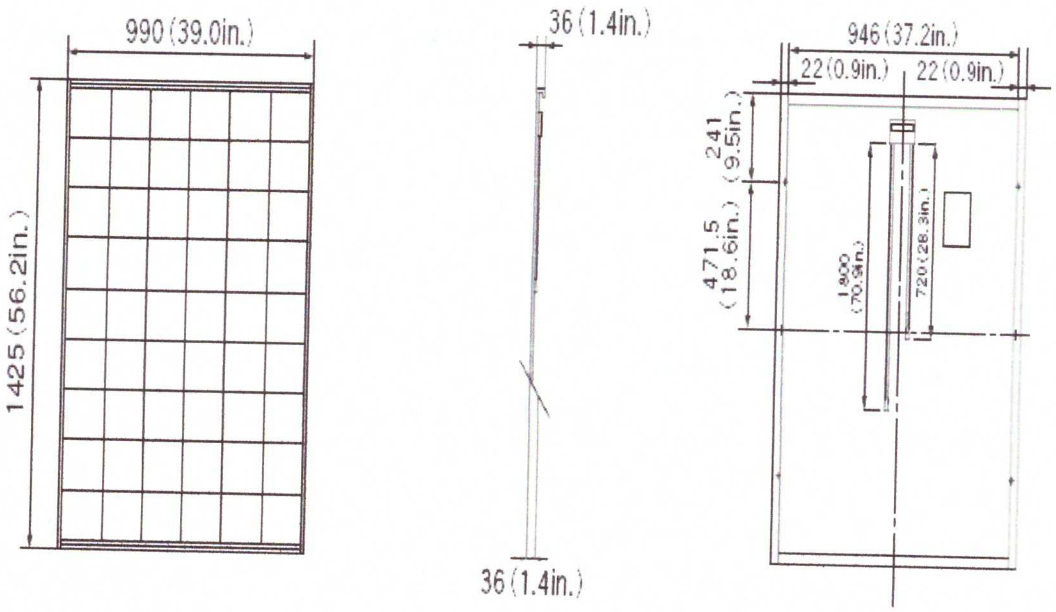
(A-5)

SPECIFICATIONS

KC200GT

Physical Specifications

Unit : mm (in.)



Specifications

Electrical Performance under Standard Test Conditions (*STC)

Maximum Power (Pmax)	200W (+10%/−5%)
Maximum Power Voltage (Vmpp)	26.3V
Maximum Power Current (Impp)	7.61A
Open Circuit Voltage (Voc)	32.9V
Short Circuit Current (Isc)	8.21A
Max System Voltage	600V
Temperature Coefficient of Voc	-1.23×10^{-1} V/℃
Temperature Coefficient of Isc	3.18×10^{-3} A/℃

*STC : Irradiance 1000W/m², AM1.5 spectrum, module temperature 25℃

Electrical Performance at 800W/m², NOCT, AM1.5

Maximum Power (Pmax)	142W
Maximum Power Voltage (Vmpp)	23.2V
Maximum Power Current (Impp)	6.13A
Open Circuit Voltage (Voc)	29.9V
Short Circuit Current (Isc)	6.62A

NOCT (Nominal Operating Cell Temperature) : 47℃

Cells

Number per Module	54

Module Characteristics

Length × Width × Depth	1425mm(56.2in)×990mm(39.0in)×36mm(1.4in)
Weight	18.5kg(40.7lbs.)
Cable	(+)720mm(28.3in),(-)1800mm(70.9in)

Junction Box Characteristics

Length × Width × Depth	113.6mm(4.5in)×76mm(3.0in)×9mm(0.4in)
IP Code	IP65

Reduction of Efficiency under Low Irradiance

Reduction	7.8%

Reduction of efficiency from an irradiance of 1000W/m² to 200W/m² (module temperature 25℃)

Product Name and Description	KC 200GT	KC 175GT	KC 130GT	KC 130TM	KC85T	KC65T	KC50T	KC40T
Part Number	**120002**	**117502**	**113002**	**113012**	**108511**	**106511**	**105011**	**104011**
Rated Power (Watts)	200.0	175.1	130	130	87	65	54	43
Series Fusing (Amps)	11.0	11.0	12.0	12.0	7.0	6.0	6.0	6.0
Current at Max Power (Amps)	7.61	7.42	7.39	7.39	5.02	3.75	3.11	2.48
Voltage at Max. Power (Volts)	26.3	23.6	17.6	17.6	17.4	17.4	17.4	17.4
Short Circuit Current (Amps)	8.21	8.09	8.02	8.02	5.34	3.99	3.31	2.65
Open Circuit Voltage (Volts)	32.9	29.2	21.9	21.9	21.7	21.7	21.7	21.7
Length (Inches)	56.2	50.8	56.0	56.0	39.6	29.6	25.2	20.7
Width (Inches)	39.0	39.0	25.7	25.7	25.7	25.7	25.7	25.7
Depth of frame (Inches)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Depth including j-box	1.4	1.4	1.4	2.2	2.2	2.1	2.1	2.1
Shipping Weight (lbs.)	40.7	35.3	33.0	33.0	24.0	18.0	16.0	13.0

All specification at 25°C cell temperature, 1.5 AM and 1000W/m^2. Wattage ratings are + 10% or – 5% (KC40T +/- 5%).
KC "T" and "TM" modules have a conduit ready junction box. "GT" modules have multi-contact connectors.

(A-6)

Model	1800U SBD with LCD	2500U SBD with LCD	2500U 208 SBD with LCD
Part Number	**52978**	**52981**	**53016**
AC Input Voltage	120 VAC (106-132)	240 VAC (213-262)	208 VAC (183-229)
Max AC Power Output (Watts)	1800	2500	2100
DC Input Voltage	156 - 400 VDC	250 - 600 VDC	250 - 600 VDC
Max DC Current	12 A	12 A	12 A
Total Harmonic Distortion	THD < 4%		
Peak Efficiency	93.6%	94.1%	
Output Frequency	60 Hz (59.3 - 60.5)		
Peak Power Tracking Voltage	156 - 350 VDC	234 - 550 VDC (at 240 VAC)	
Cooling	Convection Cooling (No fan)		
Dimensions (in.) (L x W x D)	17.1 x 11.6 x 8.4		
Weight (lbs.)	59.4	71.0	

Model	Efficiency	DC Voltage Input	Continuous Power	AC Volts Output	Dimensions	Weight	MSRP
SWR 2500U	93%	275-550 V	2500 W	240 VAC	8.4" x 11.6" x 17"	70.5 lbs	$2,750.00
SWR 2500U SBD (with LCD display)	93%	275-550 V	2500 W	240 VAC	8.4" x 11.6" x 17"	70.5 lbs	$2,950.00
SWR 2500U SBD 208 (with LCD display, for connection to 3 phase utility systems)	93%	275-550 V	2100 W	208 VAC	8.4" x 11.6" x 17"	70.5 lbs	$3,050.00
SWR 1800U	93%	150-400 V	1800 W	120 VAC	8.4" x 11.6" x 17"	59.5 lbs	$2,350.00
SWR 1800U SBD (with LCD display)	93%	150-400 V	1800 W	120 VAC	8.4" x 11.6" x 17"	59.5 lbs	$2,550.00

Communication Accessory Equipment

SBD	2 line LCD display with back light for Sunny Boy inverters	$289.00
SBSL	Cover lid for Sunny Boy inverters	$139.00
SB RS-232-N	RS-232 Module for use in Sunny Boy inverters	$179.00
SB RS-485-N	RS-485 Module for use in Sunny Boy inverters	$179.00
SB 232 SERV	Sunny Boy PC Service cable	$229.00
SB NLM-N	Power Line Carrier Module for use in Sunny Boy Inverters	$159.00
XPCP	Power line carrier phase coupler for 120/208/240 VAC circuits	$79.00
PZZ001	Power line carrier coupler for 208/240 VAC 3-phase circuits	$109.00
XPPF	Plug-in filter for 120 VAC wall sockets, 5A	$62.00
XPF	In-line noise filter for 120/240 VAC circuits	$123.00

Monitoring and Data Collection Equipment

SBC Light	Sunny Boy Control Light	$669.00
SBC	Sunny Boy Control	$1,125.00
SBC-485	Sunny Boy Control with RS-485 communication card	$1,295.00
SBC Plus	Sunny Boy Control Plus with 8 analog inputs and additional port	$2,250.00
SBC Plus-485	Sunny Boy Control Plus w/ RS-485 communication card	$2,395.00
RS232 Cable	RS232 Communication Cable, 15 meter	$110.00
RS485 Cable	RS485 Cable Communication Cable, 15 meter	$110.00

3/03

(A-7)

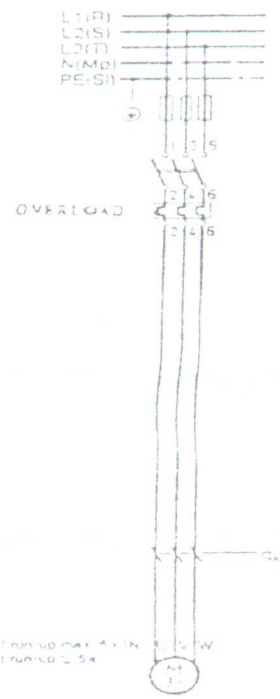
جدول ١١-١٣

جدول لقيم تشغيل ماتور حثي مباشرة على الشبكة.

قدرة الماتور (KW)	التيار الاسمي In (A)	سمك الكابل qN (mm)	اعلى قيمة لطول الكابل - نحاس (m) Lmax, m Cu	قيمة OVERLOAD (A)	قيمة الفيوز (A)
0.06	0.22	1.5	2800	0.2-0.32	1
0.09	0.33	1.5	1890	0.3-0.5	1
0.12	0.42	1.5	1400	0.3-0.50	2
0.18	0.64	1.5	950	0.45-0.75	2
0.25	0.58	1.5	700	0.7-1.1	2
0.37	1.22	1.5	510	1-1.6	4
0.55	1.5	1.5	410	1-1.6	4
0.75	2.00	1.5	310	1.4-2.2	4
1.1	2.6	1.5	240	2-3.2	4
1.5	3.5	1.5	170	3-5	6
2.2	5.00	1.5	120	4.5-7.52	10
3.00	6.6	1.5	90	4.5-7.5	16
4.00	8.5	1.5	70	7-12	16
5.5	11.5	1.5	50	7-12	20
7.5	15.5	2.5	65	11-18	25
11	22	4	75	16-25	35
15	30	4	55	20-32	50
18.5	37	6	65	30-45	63
22	44	6	55	30-45	63
30	60	10	65	40-63	80
37	72	16	90	60-90	100
45	85	16	75	60-90	125
55	105	25	95	80-130	160
75	140	35	100	100-160	200
90	170	50	120	130-210	250
110	205	70	140	160-210	250
132	245	95	160	160-250	315
160	295	120	165	200-400	400
200	370	185	205	200-400	500

D.O.L. Starting

from 0.06 kW up to 200 kW



- * الجدول يصلح لماتور حثي ٣ فاز (1500 rpm)
- * يعير ال (O.L) على التيار الاسمي للماتور
- * نوع الكونتاكتور من حيث التشغيل (AC 3)
- * قيمة جهد التشغيل هي (380V)
- * أعلى قيمة مسموح بها للهبوط في الجهد هي (3%) من قيمة جهد التشغيل.
- * تم حساب الهبوط في الجهد حسب المعادلة التالية:

$$u = \frac{1.73 * L * In * \cos\Theta}{x * qN}$$

Voltage drop u : max 3% of 380 V

عندما تكون L اكبر من اعلى قيمة ل **Lmax** يجب حسابها.