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A Seawater Desalination Paradigm Utilizing Solar Energy

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Abstract: The scarcity of potable water added more pressure on the Palestinian and is considered obstacles in planning for sustainable development. It is so important to find alternatives that have no adverse effect on the environment and at the same time provide genuine solutions to the available resources. In this paper a new paradigm for desalinating brackish and seawater is introduced. The proposed system is technically descried with size optimization that may cater for providing definite amount of potable water serving small communities. The main driving energy, electrical and thermal, is converted from the all around year available solar radiation.

Key words: Membrane module, solar energy, seawater desalination, Gaza Strip.

1. Introduction

Occupied Palestinian territories (oPt) are experiencing a severe water crisis caused mainly by the lack of control over the Palestinian water resources. While the present average per capita water consumption by the Palestinian population reaches about 50 liter per capita per day (LCD), representing only around 50% of the World Health Organization's (WHO) recommended minimum consumption of 100 LCD. The main problem for the scarcity of water is the inability of the Palestinians to access, manage or utilize their natural resources, including water. And while the Oslo accord and agreements signed included issues related to water management and allocations, the implementation was inadequate and controlled by the Israeli authority.

Main water resources in the West Bank and Gaza Strip areas are the water aquifers. Palestinians have no access to Jordan River basin and surface waters. In Gaza Strip, the only water resource is the coastal aquifer, which is believed to be highly contaminated [1] by the infiltration of the sewage and solid waste leachate. It has been over pumped resulting in lowering the groundwater table below sea level resulting in the intrusion of the saline seawater into the aquifer [2]. This has lead to adverse problems that affect the public health and the environment. The problems are intensified by the Israeli measures taken in particular against the Gaza Strip. Since 2006 and after the Israeli occupation redeployed its army surrounding the strip, Israel has waged a war against Gaza Strip that did not spare any infrastructure, public utilities, etc.. The consequence on the water and sewage networks is devastating. As part of the water consumed by the Palestinians in Gaza strip is purchased from the Israeli water company Mekorot, Israel monopolized this water to put more pressure on the Palestinians.

In addition to monopolizing water supply, Israeli declared its embargo on Gaza Strip by not supplying either the electric power, which amounts at 120 MW (represents 65% of the total electric power demand) or the conventional fuels needed for the electric power station, automotive, industries and households [3].

The long time occupation of the Gaza Strip and the

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continuous tough measures imposed by the Israel occupation has lead to a devastated economical situation. The economical situation is worsened even more as the population growth rate is high, and so the population density over the geographic area of the strip.

The current continuous pressures imposed on Gaza necessitate genuine solutions that mitigate the adverse public health and environmental problems and ensure the supply of fresh water in reasonable prices. One of the technical solutions available is the distillation of the seawater. Such solution has serious limitations as it requires large quantities of thermal energy. An alternative promising solution is the use of the membrane desalinization system that requires reasonable quantities of thermal energy. Such quantities could be secured from the all-around-the-year available solar energy over Gaza, which receives an average of 230 W/m^2 of solar insolation on horizontal surface. The monthly daily average of total insolation on horizontal surface could be seen in Fig. 1.

The utilization of solar energy using solar energy conversion systems is promising. Both electrical and thermal energies converted by solar energy systems represent clean and feasible alternatives compared to the energy produced from conventional sources. The utilization of solar energy in Palestine for heating water for domestic uses is considered high in the region. The PCBS [4] published statistical document indicated that more than 65% of the Palestinian households in the

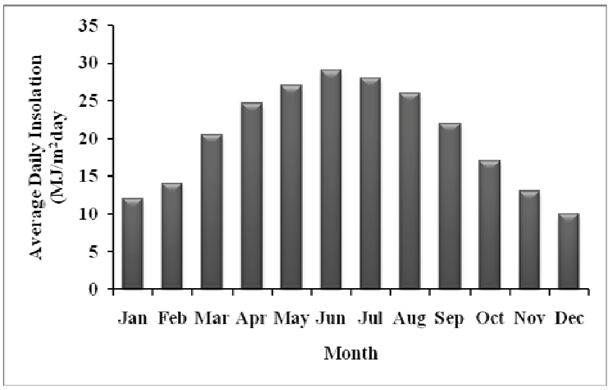

Fig. 1 Average daily solar radiation measured for Gaza.

Source: Palestinian Ministry of Transport, Meteorological Office.

West Bank and Gaza Strip are equipped with solar domestic hot water systems. The solar hot water systems are manufactured locally in both Gaza Strip and the West Bank and the range of temperature for low and medium solar thermal collectors produced is 30-60 ℃ and 70-120 ℃ respectively with very competing prices. They are used mainly for domestic uses, as it the case with low temperature collectors, as well as for some industrial applications where medium temperature collectors of evacuated tubes are preferred. Evacuated tubes collectors produced with selective coating and best techniques may work in temperature range of 80 ℃ to 150 ℃. This range of temperature could be easily utilized for many applications, including desalination of sea water. Depending on the material and the design used, a price for a 1.0 m^2 evacuated collector panel is in the range US $80-150.

In addition to thermal conversion of solar energy, electrical energy could be directly produced through the use of Photovoltaic (PV) cells. The advancement in PV cells production techniques has lead to conversion efficiency ranging from 15-18% and subsequent low production cost. However, the ongoing advancement on PV cells' performance indicate that in few years time the conversion efficiency will be increased to the extent that PV cells would provide major electric power to communities all over the world. The 2007 record for World solar PV market estimated that some 2.8 Gigawatts peak (GWp) were installed. Due to solar technical feasibility of the solar PV and their environmental friendly applications in addition to the high increase in prices of the energy produced from conventional energy sources, demands on PV cells were increased and hence their prices were reduced to the extent that people can afford buying them and using them for domestic applications. The US Environmental Protection Agency estimated that the average cost per installed watt for residential sized system; including panels, invertors, mounts and electrical items, was in the range US $7.5-9.5 in 2006 [4], and that the price will drop significantly in the coming few years.

In oPt solar energy is widely used for heating domestic water using the solar domestic hot water (SDHW) systems. The PCBS [5] in 2008 estimated that more than 70% of the Palestinian households have SDHW systems installed and hence an estimated contribution of household energy that reaches 15% is easily secured by using solar energy. International funding agencies have also funded several programs were PV panels, high concentration thermal collectors, and other solar energy systems were installed serving Palestinian communities [6].

This paper introduces an integrated desalination system that converts solar energy to thermal and electrical energies to drive the system components. Seawater feeds into the system and fresh water is produced through certain procedures. The recommended system output of desalinated water is in the range 30-50 liter per hour. The system is meant to serve a small community with low production cost. It is based on Khatib [7] proposed system.

2. Methodology

The new proposed paradigm is planned on two main assumptions:

(1) It should be driven relying on a monopoly-free energy source and that such energy source is available round the year.

(2) Most of the technology used should be locally available with competing prices and minimum O&M cost.

The first assumption could be secured using the available renewable solar energy which could be converted to thermal energy using one of the known concentrating solar collectors that could be integrated with a desalination system and harnessed to deliver the required amount of heat needed to drive the system. Electrical energy required to drive pump systems could also be provided using the Photovoltaic panel system. The second assumption could be based on low-thermal energy membrane module that utilized the reverse osmosis principles. In reverse osmoses membrane the membrane permeates the solvent and retains the solute. Such process that could be performed with low thermal energy however, it requires high pressure when working with seawater and less for brackish water.

3. System Design

The design of the system is based on integrating three major technical subsystems (processes) that start with feeding seawater and end with desalinated water production. The Membrane module subsystem extends from the seawater inlet pipe to fresh water outlet pipe. The thermal energy delivery subsystem utilizes solar energy in converting it into heat using the evacuated tube collector technology and delivers the proper thermal energy to the membrane subsystem through an effective heat exchanger. The third subsystem is the electric energy conversion system that uses PV panels to produce the proper electric power capable of driving the pumps installed and to provide energy for the control panel.

3.1 Membrane Module Subsystem

Mediterranean Sea is an open sea with its water containing ions such as Na^+, Ca^{2+}, K^+, Mg^{2+}, and Cl^-. And although open seas are the same but the total dissolved amounts are subject to local conditions. A typical composition of seawater has a total salinity of 36,000 ppm [8]. In addition to salinity, seawater includes suspended matters, such as clay, sands and microorganisms, with sizes varies from 5×10^{-2} to 0.15 μm. In the proposed design a Reverse Osmoses (RO) membrane module. The RO module performance depends mainly on three variables:

(1) The Osmotic and operating pressure (π) of the solution which can be expressed in temperature (T) in degree K, the Universal gas constant (R) equals to 8.314 kPa m^3/kg-mol K, and the concentration of all constituents ($\sum X_i$) that can be easily measured at kg-mol/m^3,

$$\pi = R\ T \sum X_i \qquad (1)$$

By assuming total dissolved solids of 1,000 ppm, an approximate Osmotic pressure could be found at about 75 kPa. In addition to Osmotic pressure, an operating pressure $P_{operating}$ is going to be needed to overcome the Osmotic pressure, the friction losses, the minor losses, the membrane resistance and the permeate pressure.

(2) The salt rejection (SR) which depends on the permeate salinity (X_p in kg/m^3) and the feed salinity (X_f in kg/m^3) and could be assessed using the correlation:

$$SR = 100\% (1 - X_p/X_f) \quad (2)$$

Current RO membranes have an SR that exceeds 99% for both seawater and brackish water.

(3) The permeate recovery (R) is a measure of the recovery rate of water product of permeates and can be defined as:

$$R = 100\% (M_p/M_f) \quad (3)$$

Where M_p is the permeate water flow rate and the feed water flow rate is given by M_f. Each quantity is measured in kg/m^3. The current value of R exceeds 50% using spiral wound membrane recommended for the proposed system.

A spiral wound membrane module is going to be used. Such membrane is composed of two flat sheets of membrane separated by a permeate collector channel material forming a leaf. One side of the four sides for this membrane is going to be kept open in order to permeate to exit. In addition to permeate the inlet feed and the concentration outlet (to waste) are assigned on the axial path of the membrane vessel. The recommended spiral wound elements are the flat sheet of a thin film composite consists of a thin active layer of one polymer cast on a thicker supporting layer of a different polymer. This type of compost membrane exhibits higher rejection at lower operating pressure.

For the membrane subsystem to operate a strainer with maximum pressure that reaches 70 kPa fitted to the pipe line that feeds seawater to the membrane system is going to be used. A pre-treatment filter that filters impurities suspended to seawater of a size range 0.15-5 μm will be used. Water that permeates (fresh) will then be collected in a special tanks made of PVC.

3.2 Thermal Energy Delivery Subsystem

Evacuated tubes collector is going to be used. This type of collectors maximizes the heat energy conversion by reducing the convection heat losses and has an optical efficiency that reaches 80%. It also has a concentrating element that direct solar radiation into the absorber located in the focal line of each evacuated tube element thus having increasing it thermal performance. An overall area of 15 m^2 of evacuated tube aperture surface will be used to cater for an average of 10 kW of heat energy required.

The fluid flow in the closed heating loop will be secured by a reciprocating pump with a head of 3 m and an input energy of 30 Watts.

A heat exchanger that passes heat at an average temperature of 40 ℃ to seawater before it permeate, is made of shell and tube heat exchanger having an overall heat transfer coefficient of 1,000 W/m^2 at a temperature difference of 24 ℃.

Integrating both membrane and thermal energy subsystems requires the use of special piping, fittings, and thermal reservoirs. The hot water reservoir (Tank) used in the integration will be insulated with proper insulation.

3.3 Electrical Energy Delivery Subsystem

The solar PV modules are going to deliver electric power to the pumps installed and to the control panel. PV panels supplying converted electric power first to charge controller that prevent the overcharging of the battery system connected to its output. Electric power be supplied then to pumps through an inverter of 120/240 VAC. A total of 2 kW electric power is required that can be secured using 8 PV panels of KG200GT type.

3.4 Seawater Pump System

The seawater pump system requires an operating pressure to withstand a calculated head losses and osmotic pressure of around 700 mH_2O. Two centrifugal pumps of 5.5 metric horse powers each is going to be installed and connected in series. Both pumps will require 700 watts of electric power that will be supplied by the PV panels.

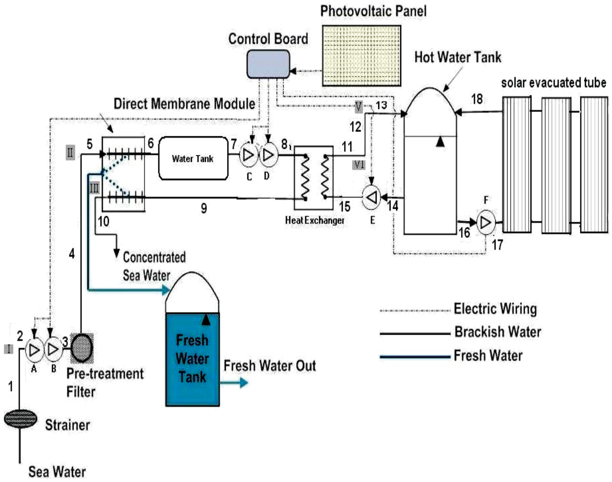

Fig. 2 Schematic plan of the desalination system with the three subsystems integrated together.

3.5 Integrated Desalination System

The suggested system is shown in Fig. 2.

The components shown in the schematic plan represent integral parts that need to be tested separately and a performance in-situ test for the whole system should be further performed.

4. Future Work

The system suggested in this paper represents a new paradigm that requires careful selection of its components, manufacturing of the rest of its parts, and optimization of its size. A further step is underway in cooperation with other international institutions to further investigate the best design and produce a pilot system for testing.

5. Conclusions

Desalination of seawater could provide an alternative solution to the scarce potable water, in particular for Palestinians Gaza Strip where the water resources are strongly influenced by the Israeli occupation. Such alternative could be practically competitive when energy required is provided by a cheap non-dwindling energy sources. The paradigm presented is an integrated system that needs to be built and investigated by testing its performance under real conditions.

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