ISSN 0126-2807

Journal of Applied Sciences in Environmental Sanitation

Volume 3, Number 3: 117-125, September-December, 2008

Open Access http://www.trisanita.org

Practical Case Study

HARNESSING SOLAR ENERGY TO MEET ENERGY NEEDS FOR WATER DESALINATION IN GAZA STRIP

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Received: 4th October 2008; Revised: 1st November 2008; Accepted: 3rd November 2008

Abstract: Water and sanitation conditions in Gaza Strip are facing severe problems in addition to poor conditions of existing municipality infrastructure that adversely affect the local environment, the ecological systems and the public health. The lack of power systems 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 seawater. A creative 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 the direct contact membrane desalination technology operated by solar energy conversion systems. The conversion system uses evacuated tubes solar collectors for providing the thermal energy needed and photovoltaic solar modules for providing the needed electrical power. System components' optimized sizes area also presented.

Keywords: Energy status, water resources, membrane desalination, solar collectors, photovoltaic solar modules

INTRODUCTION

The Gaza Strip forms part of the coastal foreshore plan bordering the Hebron Mountains in north-east, Negev desert in the south-east and Sinai desert in the south. The topography of the area varies from 0 m at the coast to around 100 m above sea level, comprises of five ridges gradually sloping eastwards. The five ridges vary from sand dunes in the coastal belt extending over a 40 km length, loessial sandy to loess soil in the eastern part of the Strip and alluvial soil in the north-eastern part [1]. The climate of the strip forms a transitional zone between semi-humid coastal zone of Israel in the North, the semi-arid loess plains of northern Negev desert in the east, and the arid Sinai desert of Egypt. The average daily temperature in Gaza Strip is 25 ^{o}C in summer and 13 ^{o}C in winter and the relative humidity varies between a minimum value of 60% to a maximum 80% in both summer and winter. The average daily solar radiation in Gaza Strip exceeds 600 W/m^2, and the average annual rainfall amounts at about 400mm. The strip extends over an area of 365 km^2 with a population that estimated in 2007 at 1,416,539 based on the annual growth rate of 3.8% [2]. This in turn makes the area densely populated with more than 4000 inhabitant/km^2. The World Bank [3] estimate of the real 2007 GDP in Gaza Strip is US$ 3,901 million, which is 14% lower than that of 1999, and based on the household income; i.e. excluding remittance and aid. The same reference indicated an increase in the poverty rate that reached in 2007 a 67%.

During the last thirty years it is very difficult for people and other vital substance to access in to or out from the Gaza Strip, in particular the fuel supplied as well as the portion of water. It makes sustainable development a real challenge to the people living there, especially with regard to securing the increasing demand on water. The humanitarian international organizations declared the situation as a crisis that needs urgent solutions. Therefore, this paper describes the status of energy and water resources in Gaza Strip. Realizing the increasing demand on water resources and the quality of water resources available in Gaza Strip, a solution is proposed by which a technique is used that utilizes the available solar energy. The technique converted solar energy to meet the needed thermal and electrical energies to drive a desalination unit based on the direct contact membrane desalination systems. Suggested system components' seizes, based on technical specifications are also introduced.

METHODOLOGY

Energy and water resources status, information and data are sought from relevant sources. The Palstinian Energy and Natural Resources Authority (ENRA), the Palestinian Environmental Quality Authoriy (EQA) and the Palestinian Water Authority (PWA) have provided essential data. Other international humanitarian organizations working in Gaza Strip have also provided updated data and information. The background information collected on the status of the water and energy sources showed a serious escalating problem facing the people and the environment.

The shortage and quality of water resourcs and the monopoly of conventional energy sources indicate that a genune solution that may mitigate both problems should be introduced. As the seawater is available and the solar energy is considered potential and as both are costeless, harnessing solar energy to meet the seawater desalination technology could be the best solution. In this context the energy required to drive a seawater or brackish water desalination unit could be converted from the solar energy; whether through its direct conversion to electrical power or indirectly to thermal energy.

Desalination technicque that uses membrane desillation methods is not complicated and proven to be effective when utilizing renewable enrgy. Because of the economical situation, the population density and the scatter of refugee camps and other communities on a narrow strip bounded in its longitudinal direction by the Mediterranean Sea, it is essential to introduce an optimized desalination system that desalinates seawater to provide a daily amount of potable water. Such system, which may produce an output potable water of 20-40 L h^{-1}, may mitigate the problem as it will cost less, requires less space and less mainatainse and may be produced and installed in several places to serve the communities.

STATUS OF ENERGY AND WATER RESOURCES AND THEIR IMPACTS

Gaza Strip gets its 65% of electrical power from Israel, which supply it with 120 MW, and from Egypt, which provide the Strip with extra 17 MW. The rest 65 MW is generated by the domestic electric power generators that run on a fully dependent Israeli imported fuel. The total 202 MW consumed does not meet the increased demand which amounts in 2007 at 240 MW [4]. The price of electricity supplied by the Israeli Electric Company to Palestinians in Gaza exceeds US$ 0.125/kWh, which is considered the highest in the region [5]. Israel allows the supply of less than 3 million liters of fuel to Gaza Strip per week and since October 2007, Israel has monopolized the supply of electricity and fuel in a way that it has reduced the electricity supplied on weekly bases and cuts or suspends the fuel supplied on regular bases [6]. The impact of power cuts affects every aspect of civilian life and in particular the capability of the Costal Municipalities Water Utility (CMWU) to pump and distribute water or process sewage system. This means adverse impact to public health, the environment and the ecological system, especially the marine one. As the CMWU is unable to treat the sewage it had no other choice but to release wastes into the sea at a rate of 40 million L day^{-1} [7] when no power is available. It is so clear that limiting supply of power to Gaza Strip is placing ever increasing pressure on providing basic services in education, health, water and sanitation to Palestinians. The limited amount of fuel supplied has caused high increase in prices and a declination of the living standards.

Water scarcity is another problem that not only Gaza Strip is facing but also the region as a whole. In the Gaza Strip, the main source of water is provided by the costal aquifer underlying the strip. This aquifer has an annual safe yield of 55 million m^3 but is being over pumped. The aquifer used to be partially recharged from the Wadi Gaza that runs from Herbon Mountains and flows through Israel before reaching Gaza. There are approximately 3,850 wells in the Gaza Strip, pumping 122 million m^3 $year^{-1}$ of water. The amount of water pumped is used for both domestic as well as irrigation. In addition, Gaza Strip receives some 5 million m^3 $year^{-1}$ of water from the Israeli Water Company (Mekorot) [8]. The over-pumping of the coastal aquifer for some time has resulted in stripping out its sustainable supply by 65 million m^3. Consequently, the aquifer's water table has been pumped far below its recharge rate, making it susceptible to severe saltwater intrusion and causing supply-induced scarcity. The over pumping of the coastal aquifer draws more than 20 centimeters from its original level which is above sea level. As the water table falls, saltwater from the Mediterranean infiltrate into the aquifer. In many parts, the water is so saline that it may damage soil and crop yields, and hence is unsuitable for irrigation. In land cultivated with citrus, which is considered the main agricultural product of Gaza strip, the intrusion of the salt water caused a decline in the quality of the crop yield [9].

The coastal aquifer is also contaminated by the improper disposal of waste matter, mainly sewage that intensifies during 2007 and 2008. Water supply network is also suffering from its improper infrastructure especially in the populated areas. It is estimated that more than 10% of the population in the strip are not connected to any type of wastewater management system, and thus dumps raw sewage onto sand dunes. Another large percentage of population uses poorly maintained septic tanks and soaking pits frequently overflow into streets and homes. These various contaminations of the Gaza water supply have drastically decreased the amount of potable water available and hence posing serious health hazards for the people of Gaza who suffer high incidence of kidney and liver complaints, high infant mortality, cancer, waterborne infectious diseases such as cholera, and intestinal parasites [10].

POTENTIAL OF SOLAR ENERGY UTILIZATION

The Gaza Strip is part of the eastern Mediterranean shore area, which has a relatively high daily solar insolation that reaches in Gaza an average of 230 W m^{-2} on horizontal surface. This is usually varies temporally during the day and the year. The average daily insulation over gaza is in the range of 10 MJ m^{-2} day^{-1} (December) and 29 MJ m^{-2} day^{-1} (June).

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 [11] published statistical document indicated that more than 65% of the Palestinian households in the 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°C – 60°C and 70°C – 120°C 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°C to 150°C. 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 1.0m^2 evacuated collector panel is in the range US$ 80 - US$ 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 (Fig. 1) 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.

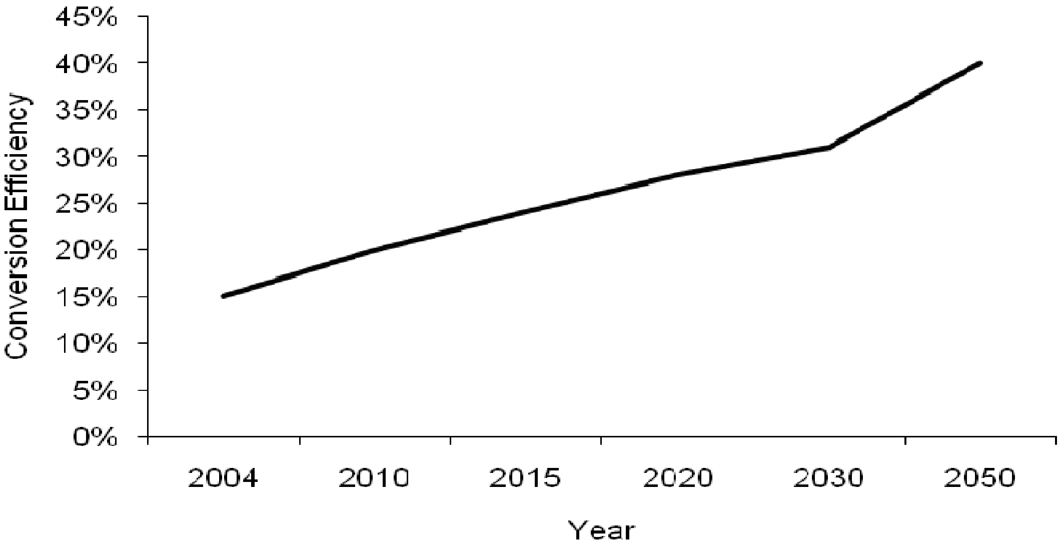

Fig. 1: PV solar cells' advancment in conversion efficiency [12]

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. It is estimated [12] 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 (Fig. 2), and that the price will drop significantly in the coming few years.

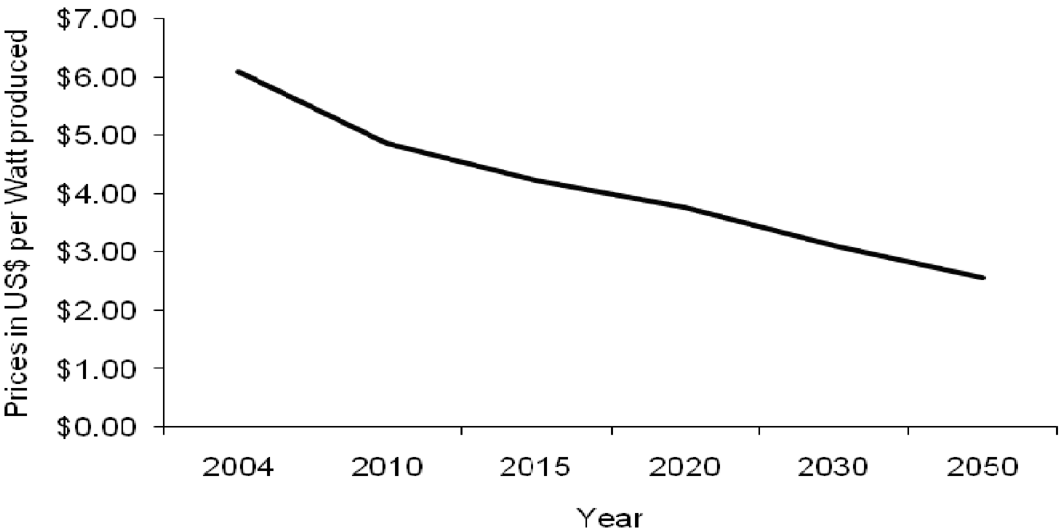

Fig. 2: PV installed system cost and provision of their future prices [12]

Life-cycle analyses show that the energy intensity of typical solar photovoltaic technologies is rapidly evolving. Recent studies suggest that technological progress has reduced the payback time to 1.5 to 3.5 years for crystalline silicon PV systems [13], which makes such technology economically feasible to be installed in areas where economical constraints exist, such as Palestinian Authority areas. It should be mentioned in this context that PV systems are installed in different Palestinian locations to serve remotely located communities that are not yet connected to the grid system. Several international funding agencies such as the Global Environmental Facilities (GEF), the European Communities (EC) and others have funded programs and small and medium scale projects in which PV arrays have been installed [14]. The prices and operation and maintenance of these systems are usually feasible and they could be employed safely to produce the required electrical energy for operating e.g. water pumps.

DIRECT CONTACT MEMBRANE DESALINATION TECHNOLOGY

The proposed technique includes the utilization of the available non-monopolized solar energy and the local technology. One of the main technologies being developed and used is the desalination techniques of sea or brackish water for overcoming the scarcity of conventional water resources. This technique is becoming worldwide an acceptable alternative to the depleted conventional water resources as it also has no adverse impact on the public health, the environment and the ecological system. In the last thirty years desalination techniques have experienced improvements and advancements in the technology and usage. In the Arab region, desalination has been promoted as an important alternative especially in the Arabian Gulf region. There, the availability of conventional energy sources in low prices has reduced significantly the cost of desalination. For other non-oil producing countries, desalination option is considered non-feasible as it requires a considerable amount of energy. However, the parallel advancement in the techniques of utilizing renewable energy sources and in particular the solar energy has made it possible for combining both techniques in building feasible desalination systems. Solar energy driven desalination technologies fall into two categories. The first category includes desalination technologies driven by heat produced by solar energy, while the second includes membrane and desalination technologies driven by electricity or mechanical energy produced by solar energy. Two critical parameters of the desalination processes are the quality of the produced water and the amount of energy required. Produced Water quality usually depends on the desalination process and should comply with the World Health Organization limits and should not totally devoid of salt [15].

The proposed desalination system for Gaza Strip is based on the direct contact membrane desalination (DCMD) technology that has high potential for drinking water production for both small and medium scale applications and it has been designed and tested [16-19] in addition to being suitable for rural areas where energy power lines are not available and/or the prices of energy produced from conventional energy resources are considerably high. The Gaza Strip could be considered a potential location for implementing such systems. The DCMD technology utilizes a membrane distillation process in which both liquid feed and liquid permeate are kept in contact with the hydrophobic microporous membrane. The temperature difference between the two solutions gives rise to a trans-membrane vapor pressure difference that drives the flux. Due to their hydrophobicity the liquid can not penetrate into membrane pores, but the vapor can pass the pores due to the vapor pressure difference. The desalination is performed at ambient pressure and maximum temperature of 90°C, which can be attained using a locally produced medium temperature thermal solar collector of evacuated tube [20].

Cheng *et al.* [21-22], Schneider *et al.* [23] and Mengual *et al.* [24] have all suggested methods of increasing the DCMD system performance and reducing their costs through the use of composite membrane. DCMD may utilize renewable energy sources [25-27] where, solar and wind energy sources may both be used for supplying the system with both thermal and electrical energy. In the system proposed, thermal energy is going to be supplied by several absorbers of evacuated tubes solar collectors. In this type of solar collector, the absorber strip is located in an evacuated and pressure proof glass tube (see Fig. 3). The heat transfer fluid flows through the absorber directly in a tube-in-tube system. Several single tubes connected to each other via manifold, make up the solar collector. A heat pipe collector incorporates a special fluid which begins to vaporize even at low temperatures. The heated fluid rises in the individual heat pipes and warms up the carrier fluid in the main pipe by means of a heat exchanger. The condensed liquid then flows back into the base of the heat pipe. The suggested total area of the each panel is 400 x 120 cm^2 which makes a total solar collector area of 9.6 m^2. Each evacuated tube absorber has a conversion factor in the range of 0.65 – 0.85 and a thermal loss factor of 0.7 – 0.2 W m^{-2} ^oC. Thus it is possible to raise the temperature of water in the range of 90-120 ^oC. To compensate any deficit in the required thermal energy, extra evacuated tubes solar collectors may be added.

The system works by pumping the sea water up through the direct contact membrane module before and after the water has been heated by the two in series evacuated tubes solar collectors. Hot water produced is going to be circulated in a heat exchanger via a solar energy driven water pump as shown in Fig.3. The seawater feed is flowed to the membrane modules in lumen side and it is heated in the heat exchange to vapor phase and then flown again in the other side where it permeate through the pores of the membrane, which allows only for vapor to permeate and blocks liquid. When the two liquids seawater with different vapor pressures are separated by the membrane, vapor evaporating from seawater with the higher vapor passes through the pores of the membrane and condensed. Therefore, fresh water can be separated from seawater. The hydrophobic porous separation membrane of polytetrafluroethylene, polypropylene or polyethylene is usually used in the process. Such technology has been produced and installed commercially in several areas around the world, e.g. [28]. The electricity required to operate the four pump units is provided by a photovoltaic panel produced from monocrystalline material capable of converting the solar radiation into electricity at a working efficiency that may exceed 15%. Few panels of 90 modules, of 0.5 m^2 each, may produce around 6 kW; an energy sufficient to power the pumps system.

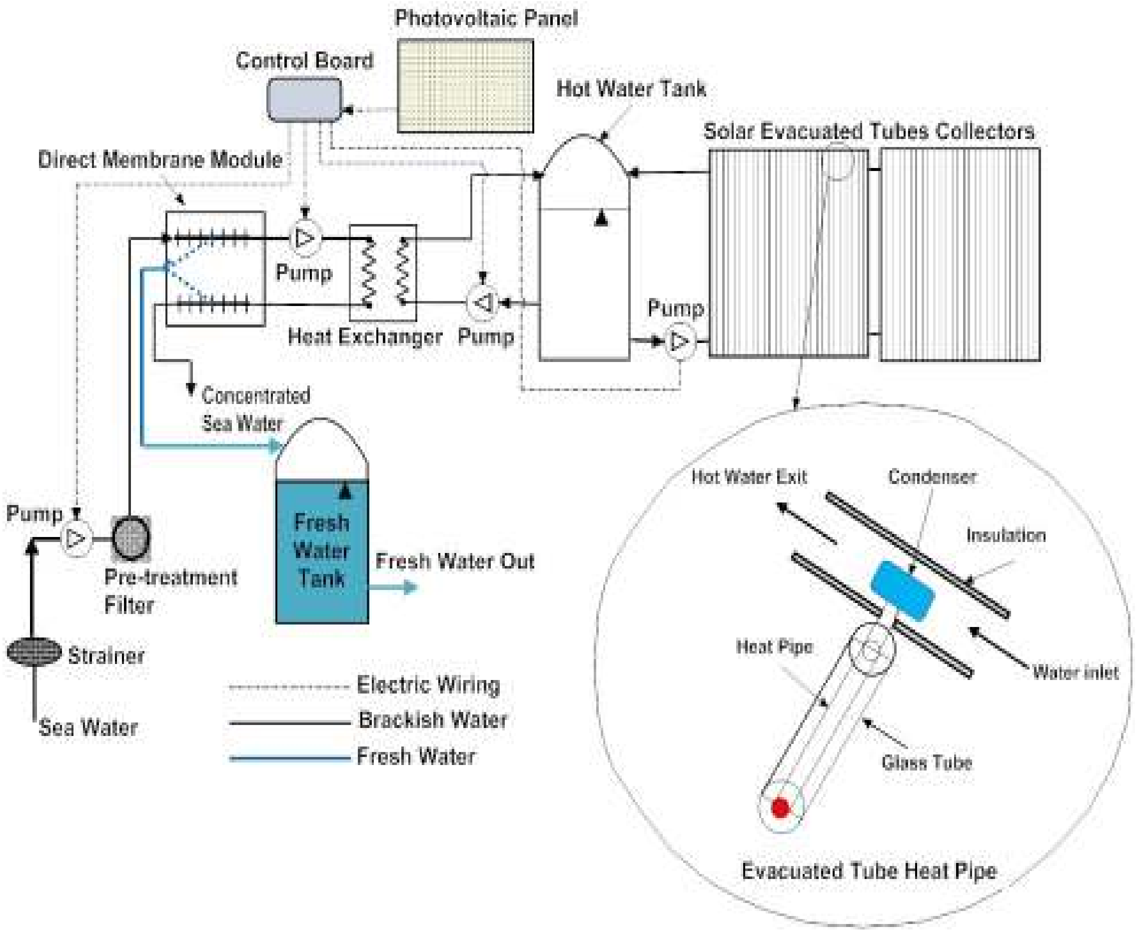

Fig. 3: A schematic draw of the system and its components

Most of the system components could be produced or purchase locally however, the proper PV panels, pumps and the direct membrane module could be imported. The experience of the working international agencies, including the United Nations agencies, the Global Environmental Facilities, and other humanitarian agencies, may contribute substantially. In Table 1, a provision of system specification is presented. The complete system shown in Fig. 4 could occupy an area of 30 x 30 m^2 and could desalinate sea water at a rate ranging from 30-50 L h^{-1}. It is however, essential to build and in-situ test a prototype system in order to effectively plan proper desalination units.

Table 1: components of the suggested desalination system

Component	Specification	Source
Direct contact Membrane Module	Plat and frame module with three champers separated by pre-evaporation membrane and cooling sheets.	Imported
PV modules	Of monochrystalline material $0.5m^2$/module with power output of 0.5Watt	Imported
Solar PV powered circulation pumps	Discharge rate of 3.5 L min^{-1} and a head of 0.5 m for circulating pump. Sea water pump is 7 L min^{-1} with a head of 1.2 m.	Imported
Heat Exchange	Shell and tube manufactured with best available material	Locally produced
Evacuated tubes solar collectors	Made of evacuated tube absorbers each with heat exchange. Collector area is not less than 4 m^2. Selective material should be used.	Locally produced
Tanks, pipes and fittings, strainer and pre-treatment filter	Good material quality	Purchased locally
Control		Designed and constructed locally

CONCLUSIONS

The paper proposes a solution to overcome the ongoing crises in Gaza Strip and mainly for meeting a portion the demand on potable water. It also highlights the potential of utilizing solar energy either in the thermal or direct electrical conversion techniques. The scarcity and quality of water that did not improve during the last thirty years, and the monopoly of both vital recourses may be the driving force for developing other independent alternative. The system could also be used in other areas located on seas to provide water for the domestic use as it has no adverse impact of the environment or public health in addition to its cost effective.

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