MULTI SOLAR DESALINATION PLANT

Eng. Ami Elazari MBA
Millennium Electric T.O.U. Ltd. P.O. Box 2646, Raanana Industrial Zone 43650 Israel
Phone : 972-9-7439490 Fax : 972-9-7453654 E-mail : Info@millenniumsolar.com

Purpose of the work

Desalination technology, which makes it possible to exploit sea water as a water source, is playing an increasingly important role throughout the world. However, its high energy consumption is costly (4-5kWh/1 cubic meter of desalinated water) and has a global environmental impact. The desalination process using solar energy in general and Multi Solar (MSS) technology specifically, would alleviate this problem, by lowering the energy consumption to 1.4 kWh/1 cubic meter of desalinated water. the desalination system which uses the membrane distillation process providing the necessary heat and electricity generated solely by solar energy using the patented Multi Solar System PV/T collectors. As illustrated in Fig. 1, the solar energy desalination plant produces fresh water by pumping sea water up through the membrane module before and after the water has been heated by the multi solar collector.

1. Scientific innovation and relevance

MSS pervaporation (known as membrane distillation) is a membrane separation process which allows gas or vapor molecules to permeate but which blocks the passage of liquids. When two liquids with different vapor pressures are separated by a membrane having this property, the vapor evaporating from the liquid with higher vapor pressure passes through the pores of the membrane and condenses. This is why fresh (distilled) water can be separated from sea water. In order to create two liquids with different vapor pressures the sea water needs to be heated to a temperature between 60ºC-70ºC. At this temperature, the molecules of the salt water and the fresh water can easily be separated. There are two types of membrane distillation: The direct contact system and the diffusion gap system (see Figure 2). The direct contact system needs coolers to cool fresh water which is used as a cooling liquid to condense the water vapor. The diffusion gap system uses cold sea water as a cooling liquid and doesn't require coolers; it recovers the latent heat of the water vapor, and is consequently relatively high in efficiency.

2. Results and Conclusions

The performance of the collector field and evaporator subsystems haven't suffered in performance decline to any appreciable degree: the total cost of water ranges from around $ 30.36m(with a lifetime of around 20 years), with the contribution of capital amortization representing about 85% of the total cost and only 15% contributed by operation & maintenance expanses; No problems have so far been encountered with any of the tube bundles; distillate conductivity has been in the range 10-20 μS/cm. This is indications that correct choice of tube and tube sheet materials have been made. This desalination technology has proved its reliability and flexibility for variable load operation and is worth serious consideration as a provider of fresh water in remote communities. The results of this study have been encouraging and it's likely that this project will be carried out in the near future. Other plans include the investigation of the use of a PV and Multi Solar arrays to power a small seawater reverse osmosis (RO) desalination system to demonstrate the technology locally and test its feasibility fro remote areas. To conclusion Based on an average daily water production of 100m3, the water cost due to capital amortization, Cwc, may be estimated as:

$$Cwc = \frac{Ccap * CRF}{Md * (0.85)(365)(20)} = \frac{(1,860,959*0.12)}{(100)*(0.85)*(365)*(20)} = \$0.36 \text{ USD per m3 of distillate.}$$

All the Electricity required in the plant is supplied by a photovoltaic power generation system made up of the 2

MSS collectors, producing total of 2.3kW per 1m. A variable voltage, variable frequency inverter connected to the photovoltaic system automatically starts up the desalination system according to the amount of solar radiation available and runs the pumps by controlling the output of the photovoltaic system. The diffusion gap system used in the demonstration test uses a plate and frame membrane module which forms three chambers; the warmed sea water chamber, the permeated-water chamber and the cooling liquid (cold sea water) chamber. The chambers are partitioned by the pervaporation membrane and the cooling sheet.

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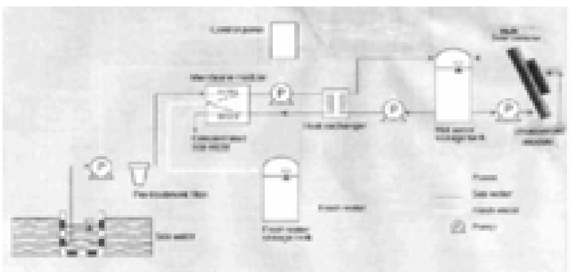

Fig 1. Flows of water and power in the plant there are two types of membrane distillation: The direct

contact system and the diffusion gap system (see Figure 2). The direct contact system needs coolers to cool fresh water which is used as a cooling liquid to condense the water vapour. The diffusion gap system uses cold sea water as a cooling liquid and doesn't require coolers; it recovers the latent heat of the water vapour, and is consequently relatively high in efficiency.

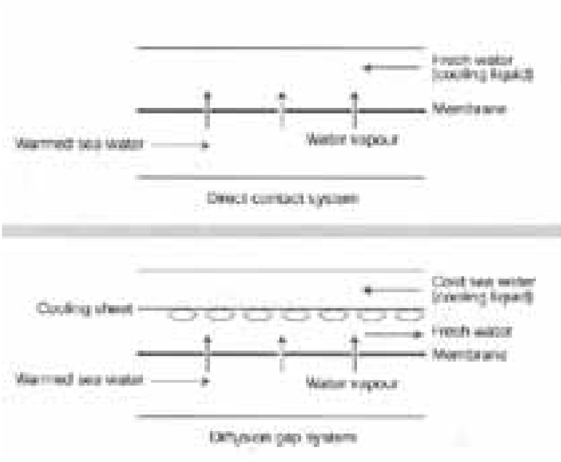

Fig *2.* Membrane distillation (pervaporation) system

Advantages of the MSS membrane distillation process include:

•Independent solar energy sources – combined thermal & electrical saving place and costs;
•Ability to operate at relatively low temperatures;
•High performance in separating salts;
•No high temperature or high pressure components;

Debris can be removed from sea water using only simple pre-treatment.

3. PLANT SPECIFICATIONS AND DESIGN FEATURES

The plant consists of three subsystems:
1. The Multi Solar Collector
2. The Heat Accumulator
3. Sea Water Evaporator

And is designed for an expected yearly average fresh 3water production of 85m/day using sea water with a salinity of 55,000 ppm TDS. A simplified schematic of the plant is shown in Fig 1. The specifications and design features of the plant are summarized in Table 1.

A bank of Multi Solar Collectors, flat plate collectors with a total absorber area of 1,862m^2 is used to provide the thermal energy required by a multiple effect stack-type (MES) evaporator having a rated capacity of 3120m/day. In order to ensure that the evaporator can run 24 hours per day during sunny days, a thermally 3stratified heat accumulator with a capacity of 300mis incorporated in the design to provide the thermal energy required during the night time. The electrical energy required by the different pumps is provided from the PV panels. Each of the subsystems is described in some detail in the following sections.

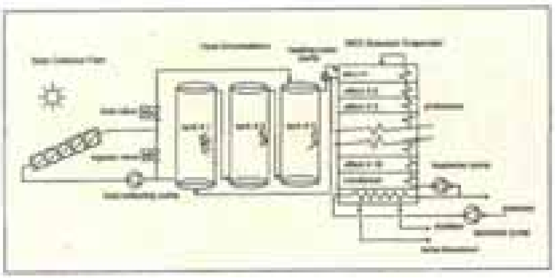

Fig 3. Schematic diagram of the solar desalination plant

3.1 solar energy collecting subsystem

The solar energy collecting subsystems converts solar energy into thermal energy when solar radiation is available during the day using a bank of solar collectors. The thermal energy is stored in the heat accumulator subsystem for hating the evaporator with minimum fluctuation in the supply temperature. This is desirable since steady operation of the evaporator near its optimum operation condition is highly recommendable. The basic unit in the bank of solar collectors in a multi Solar collector which is described as follows: The **Multi Solar PV/T technology** (**MSS**) is an innovative, patented (PATENT NO 5522944) Solar PV/Thermal System that makes it possible to convert solar energy into thermal energy and electric energy at the same time using a single integrated collector. The Multi Solar Collector, an innovative device that collects the visible & infra-red side of the spectrum, cools the PV cells in order to generate more electricity and makes the heat available for thermal use in the building. The MSS behave like a "living" skin surrounding the building, allowing the flow of water/air, capturing heat and storing it in an insulated tank, thus making it available for the heat control of the living environment while the PV cells that are cooled by water flow in pipes and air, generates 30% higher PV efficiency for production of electricity.

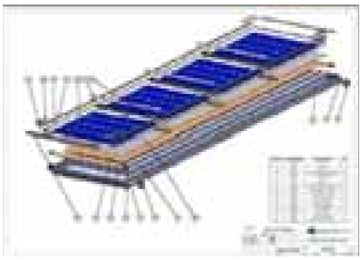

Fig 4. The combined MSS (PV/T) Collector

Each panel consists of 10 individual tubes arranged in parallel. The heat collecting water moves inside the centre tubes in a parallel/series arrangement. Each panel has an absorber area of $2.77m^2$ and the selective coating on the absorber plates has an absorbtivity of 91% and emissivity of 0.12. The collector bank consists of 672 panels making up a total collector absorber of $672 * 2.77m^2 = 1{,}862m^2$.

14 panels are connected in series to form on array and two such arrays are combined to form a

single group of collectors with its own support structure. All the groups are then arranged in a U-shape and connected in parallel. Each is provided with two isolating valves – at inlet and exit, a drain valve, and two air vents.

3.2 Heat Accumulator Subsystem

The heat accumulator subsystem is designed to provide thermal energy to the evaporator during its 24 hours per day operation. It consists of three carbon steel tanks with a total capacity of $300m^3$ and contains hot water at atmospheric pressure that can be range in temperature between 60ºC and 95ºC. The tanks are insulated with a 100mm layer of fiber glass to minimize heat loss to the ambient air. All three cylindrical tanks have the same internal diameter of 3.8mm and wall thickness of 9 mm. Referring to Figure 1, the heat collecting water from the collector bank is introduced at the top of tank No. 1 (high temperature layer). The heat collecting water to the collector bank is taken from the bottom of tank No. 3 (low temperature layer). Heating water to the evaporator is drawn from the top of tank No. 1 and returns to the bottom of tank No.3. The water is therefore stratified in such a way that the top water layers of tank No.1 are always at the highest temperature and the bottom layer of tank No. 3 at the lowest temperature.

3.3 The MES Evaporator & Membrane Distillation

In order to make solar desalination more efficient, a horizontal tube, thin film multiple effect evaporator (MES) is used with a rated capacity of 120m/day. The general principles of the MES process are illustrated as follows. Preheated feedwater is sprayed on the top of the first effect tube bundle and descends down the evaporator stack, flowing as a thin film over each succeeding effect tube. The feedwater flashes and thereby is cooled by several degrees as it passes from one effect tube to the next. It is rejected at the bottom of the last effect tube as a cool concentrated brine which is discharged to the sea. In the top effect tube, heating water from the accumulator is used to partially evaporate the thin seawater film on the outside of the tubes. The generated vapour passes through demisters to the inside of the tubes in the second effect tube where it condenses to form part of the product. Simultaneously, it causes further evaporation from the external seawater film and the process is repeated from effect tube to effect tube down the plant. The heat input from the evaporator is thus used over and over again in successive evaporation/condensation heat exchanges in each effect tube to produce more product and new vapour, thereby obtaining a maximum quantity of fresh water with minimum heat input. The vapour generated in the last effect tube is condensed in a seawater is used as feedwater to the evaporator with the remaining seawater rejected to the sea.

4. PLANT PREFORMANCE

Fresh water production varies with the solar radiation. The plant is easy to operate and produced 40 liters/hour, on average. Its performance is stable, even with considerable fluctuations in the temperatures and the amounts of energy provided by the solar sources.

The solar energy sea water desalination system using the membrane distillation process has several advantages.

The system:

- •Doesn't require high-pressure pumps (as in the reverse osmosis process) and consumes less electricity;
- •Uses simple equipment;
- •Requires no expert maintenance;
- •Has no need for batteries;
- • Can be installed at locations without an electricity supply;
- •Incurs low running costs by using solar energy.

Out of the total amount of solar radiation incident on the solar collectors, 60% is converted into thermal energy and 15% is converted into electrical energy. Some of the heat collected is also lost to the environment by the heat transfer from the piping system, the accumulator tanks and the evaporator. The heat losses depend to a large extent on the average collector water temperature as well as the ambient temperature.

Percent (%)	10_6 kcal	Energy Type
100	79.6	Incident solar radiation
36.4	29.0	Collector and piping loss
63.5	50.6	Collected heat and accumulator
8.9	7.1	Accumulator heat loss
54.8	43.6	Heat to evaporator
7.4	5.9	Evaporator heat loss
47.4	37.7	Net heat to evaporator
-0.1	-0.1	Heat stored in accumulator

Fig 5. Heat balance of the solar desalination plant

It can be seen that out of 100 units of solar radiation falling on the collector field, 63% is actually converted into heat and transmitted to the heat accumulator. Therefore the amount of collector and piping loss is 37%.The accumulator

heat loss amounts to 8.9%. The heat supplied to the evaporator is 54.8%.

The monthly efficiency is defined as the monthly amount of heat collected by the multi solar collector field divided by the amount of solar radiation intercepted during the month by the absorber plates of the collectors. The efficiency appears to achieve value of 55% with the lower values measured during winter months and higher values during summer months.

The performance of the evaporator is normally measured in terms of its specific heat consumption (SHC) which indicates the amount of heat required to produce one unit mass of distillate and is usually quoted as kcal/kg. An increase in the SHC usually means that salt scale deposition on the tube bundles is taking place and an acid wash needs to be undertaken to remove it. The results clearly indicate that the performance of the evaporator was maintained at its normal values and no scale is evident.

5. ECONOMIC CONSIDREATIONS

Capital and operating costs as well as the cost of water produced by the Multi solar Desalination Plant have been calculated to assess economic performance of the system. The capital cost figures were determined from actual prices provided by the plant manufacturer. The calculations of the water cost are based on the following economic assumptions:

Evaporating lifetime: 20 years Heat accumulator lifetime: 20 years Multi Solar collector lifetime: 20 years Interest rate: 8% Scrap value: 0 Plant availability: 80% (7,446 hours per year). The following capital costs are based on actual cost values submitted by the manufacturers:

1. Evaporator: $199,180 USD
2. Heat accumulator: $91,304 USD
3. MSS Collectors: $1,024,100 USD ($550 USD per Sqm)

Local fabrication and installation costs were estimated at 30% of the sum of the above three capital cost components which results in an amount of $394,375 USD. Transportation costs amounted to $152,000 USD. Thus the installed capital cost of the plant is:

$199,180 + $91,304 + $1,024,100 + $394,375 + $152,000 = $1,613,772 USD.

Based on an average daily water production of 100m,

the water cost due to capital amortization, Cwc, may be estimated as

Cwc = Ccap * CRF = (1,860,959*0.12) = 3

$0.36 USD per mof distillate.

Md * (0.85)(365)(20) (100)*(0.85)*(365)*(20)

Where *Cap*is the total plant capital cost, Md is the average daily water production and CRF is the capital recovery factor estimated at 0.12

The operation and Maintenance (O&M) costs consist of the following main cost components:

Cost of chemicals (antiscalant for sea water treatment, corrosion inhibitor for collector fluid and sea water disinfectant to inhibit bacterial growth); spare parts costs; cost of operation and maintenance personnel and cost for electrical power consumption. [6]

Belgard EV is used as the antiscalant; it is added to the feed water at a concentration of 10 ppm. Nalcool is used as a scale inhibitor for the solar heat collecting recirculating water and its concentration in the heat collector water is 500 ppm. Sodium hypochlorite is used as a disinfectant for the sea water and product water with a dose rate of about 18 ppm. The water cost due to operation and maintenance, Cw, O&M expenses can thus be obtained by dividing the total amount of water produced during the year. The cost of water due to both annual capital amortization and O&M costs can thus be obtained by adding together both contributions. It can be seen that the contribution of capital amortization to the water cost is about 85% with only 15% contributed by operation and main.