AGRISCIENCE AND TECHNOLOGY
Armenian National Agrarian University
ԱԳՐՈԳԻՏՈՒԹՅՈՒՆ ԵՎ ՏԵԽՆՈԼՈԳԻԱ АГРОНАУКА И ТЕХНОЛОГИЯ
International Scientific Journal
ISSN 2579-2822
Journal homepage: anau.am/hy/teghekagir

UDC 628.16.067.1+621.31

Receiving Irrigation and Drinking Water Together with Electricity in Remote and Arid Areas Using Membrane Desalination Device

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ARTICLE INFO

Keywords:
desalination,
membrane distillation,
solar energy,
fresh water,
photovoltaic panel

ABSTRACT

The availability of irrigation and drinking water, as well as water supply for agricultural purposes are important requirements for living in remote areas. The hybrid desalination device has been designed and tested under field conditions. In the mentioned device the electricity is produced with the help of absorbing solar energy by PV panels and water desalination process is performed due to thermal amount released from its heating. The novelty of this system is the structure of the device, which combines a PV panel and a MD desalination unit. The pilot plant had a total yield of 9.6 kg/m^2 and 680 W h/m^{2}day. The suggested device is a self-supply one that produces water for aeroponic and hydroponic (of drip and flow style) irrigation systems. It is also a means for satisfying the needs of drinking water and electricity.

Introduction

Water and energy are the two most essential substances for life sustaining. Supplementing the deficiency of high-quality water resources has become an important priority, especially in remote, arid and semi-arid regions. As these regions are characterized by sunny and warm climate, as well as by enormous ground resources and sea water, the lack of clean water can be supplemented by thermal desalination and the electricity can be received through solar energy. Seawater and ground saline water are inexhaustible resources for getting pure water. The total dissolved solids (TDS), which averagely make 1–45 g/L, must be decreased to the required norms for drinking and irrigation purposes.

Multi-Effect Distillation and Multi-Stage Flash equipments (Hum, Tsang, Harding, Kantras, 2006, Danald, Kathlcen, Ferguson, 2004) are mainly used for desalination of seawater and ground water. In these equipments the latent heat of evaporation is used in turn at all stages and in case of low atmospheric pressure the secondary vapor energy can be used. Evaporation processes are used for large scale desalination cases and require high capital investments and also have high energy cost. Chemical method is used for supplying pure water to plants, electric power stations and boiler-houses. In case of high salt concentrations problems, connected with the amount of reagents and recovering, increase the exploitation expenses, thus, the process becomes

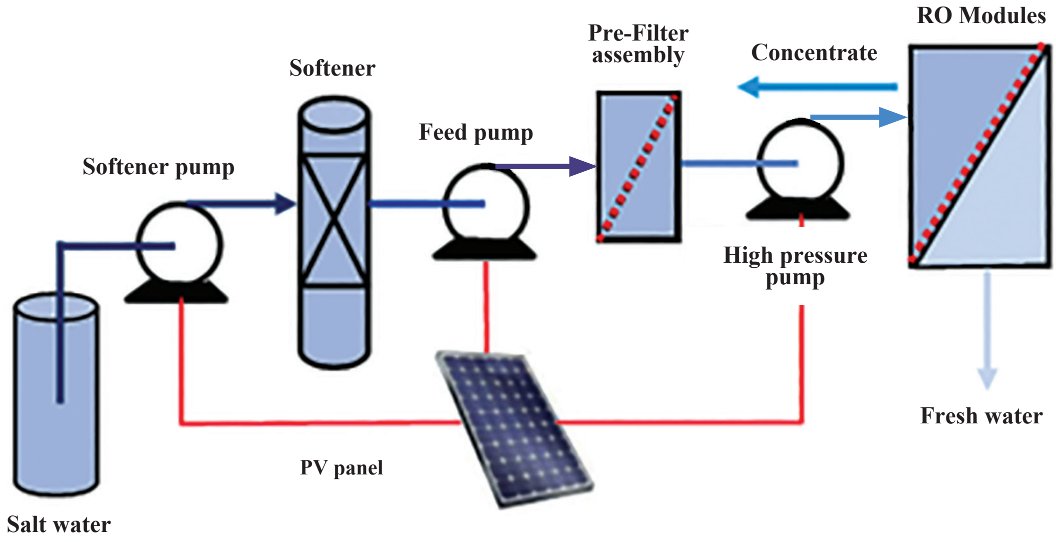

Figure 1. Simple reverse osmosis system with integrated PV panels.

economically unprofitable.There are also ecological problems related to environmental pollution. Solar still (SS), membrane distillation (MD), reverse osmosis (RO) processes are used for production of small amounts of drinking water and for not large irrigation systems (aeroponic and hydroponic) in remote and arid areas.

The solar still technology is a practical method to get fresh water from saline solutions by desalination (Pramod, 2018). The process, which is similar to the natural hydrological cycle, takes place in a "greenhouse" box and demands only solar energy. Solar still devices are simple and of easy maintenance. However, passive solar still devices have a low thermal efficiency coefficient (40 %) and the output is approximately 2-3 l/m^{2}day (Shailesh, Sorabh, 2015, Al-Karaghouli, Renne, and Kazmerski, 2010).

The membrane distillation (MD) process is a prospective method for concentrating and desalinating the aqueous solutions using solar energy (Alanezi, Mohammed, 2018, Rahman, 2013, Dytnersky, Hakobyan, 1990, Hakobyan, 2011). The principle of MD is the following: by means of low potential energy, on the both sides of the membrane, a temperature difference is established. The volatile molecules (in this case molecules of water), originating from the evaporation of heated solution, pass through the membrane and condense on the cold side, resulting in an overall transmembrane flux. The molecules of water vapor transfer through the pores of the membrane from the high pressure side to the low pressure side. The thermal energy consumption in this device is 175-350 kWh for getting 1m^3 pure drinking water and the productivity is within the range of 6.8-9.5 kg/m^2 h (Chafidz, Faisal, et al, 2001, Kiefer, Spinnler, Sattelmayer, 2018).

In recent years reverse osmosis (RO), one of the membrane processes, has been widely used for desalination (Ghermandi, Messalem, 2009). Reverse osmosis operates under high osmotic pressure on semipermeable membranes without phase changes and at environmental temperatures. Filtration process is accompanied by separation of salt ions from solution. RO operating pressure ranges from 17 to 27 bars for brackish water and from 55 to 82 bars for seawater. It has been calculated that in case of seawater desalination the expenses of preliminary water treatment can comprise up to 60 % of the whole process. Reverse osmosis systems can be coupled to PV panels to desalinate water (Hasson, Drak, Semiat, 2001, Biltona, Kelleyb, Dubowskyb, 2011).

Desalination processes by reverse osmosis require large capital investments and are not suitable for use in case of high concentration of dissolved salts. Besides, membranes used for RO are very sensitive towards environmental active chlorine and pH.

Thus technological schemes, which are somehow applicable, can be conditionally divided into the following blocks: 1.Desalination block, 2.Thermal energy providing block, 3.Electric power providing block, 4.Block providing process operation (heat exchangers, pumps, valves, regulators, measuring and recording devices).

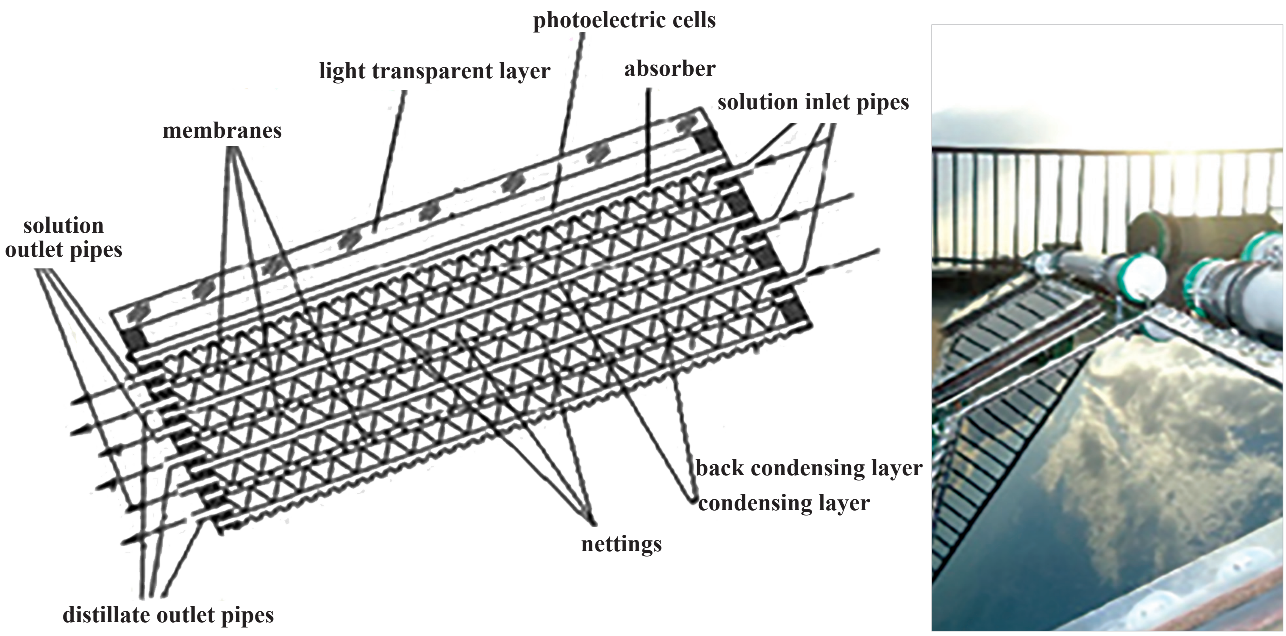

Figure 2. The construction of the desalination device with integrated PV panel and its photo.

Electric power providing block and also PV panels can be used for domestic demands in remote areas. The photoelectric processes are the most applied technologies for generating electrical energy. Photoelectric elements absorb electromagnetic rays of light, both from infrared and visible spectra. The main objective of PV panel is to absorb maximum solar radiation in order to ensure high efficiency. In this system efficiency coefficient of converters is 15 % (Kabir, Kumar, 2018). Only a part of the visible spectrum is converted into electrical energy. Most of the absorbed radiationis, which are not converted by solar cells, result in an increase of the temperature of the elements and in a decrease of the electric efficiency. The amount of absorbed energy of a solar cell depends on the location, season, day and hour.

In remote areas, in case of small productivity and not large agricultural farms, when we want a small, portabl device with easy maintenance to provide water amount about 100 to 500 liters a day, the use of presented schemes is quite problematic. Thus, a problem appears to design a hybrid solar distillation device with integrated photovoltaic panel, which can be used for drinking and irrigation (aeroponic and hydroponic of drip and flow style irrigation systems) water production in remote arid communities and in small sunny areas, using the positive characteristics of these technologies. The device can receive also electricity together with water production, besides, it occupies small ground areas and operates with high thermal efficiency.

Materials and methods

The designed device is a greenhouse box heat trap with a glass covering. The entire desalination process of seawater which means heating, evaporating, condensing and the multistage use of heat and electrical power generating is established in a single device. A photovoltaic transmission block is implemented in the form of a solar cell attached to the surface of the front thermal transmission layer, located in the device.

The constructions of the flat combined MD desalination device and pilot device are shown in figure 2.

The photovoltaic block consists of the absorber with photoelectric cells attached to the top and is installed in the front of the device. There is an air gap between the absorber and the light transparent glass cover. The distillation block is implemented with the multistage membrane and is made of layers of successive similar stages. Each stage includes a layer of micropore membranes, which are covered with the support netting layers on both sides. The stages are separated from each other by condensing layers. Each of the distillation block stages has a saline solution inlet pipe, a distillate outlet pipe and a concentrated saline solution outlet pipe. The front distillation layer, which is located towards incident solar rays, is bordered by the absorber, which has a grooved surface.

The pilot devices are 55 cm long, 30 cm wide and 3–7 cm thick. The desalination experiments were performed on a sample taken from the Black Sea. The TDS were 17.5 g/L.

The temperature of the seawater at the inlet of the device reached maximum to 50°C during the day. The water hadn't been treated before the desalination process. The experimental observations of MD solar desalination devices were made in Yerevan city (Republic of Armenia), which has a geographical latitude of 40°11′ N and a geographical longitude of 44°31′ E. The devices were set towards south with their absorbing surfaces and had a slope of 35°. The tests were held from 9:00 am to 7:00 pm and the distillate was taken once per an hour during the whole day. The main tests were performed during July. The recorded ambient temperature was in the range of 28°C–37°C. The values which were measured during the experiments were the following: the temperature of the solution, the ambient temperature, the solar radiation, the concentration of saline solution, the concentration of dissolved salts in the distillate, the electric current and voltage.The intensity of solar radiation striking a horizontal surface was measured by the pyrometer "Apogee PYR-pA5". The voltage and electric current were measured by the multimeter UNI-T (THERMOPROZESS Gruppe, Germany).The total amount of dissolved salts was measured by the Hanna Instruments HI 86301 set with an accuracy of 1 mg/L. The material of the membranes was PTFE, and the material of the support was PP. The thickness of support was175 µm, the pore size was 0.22 µm, and the porosity was 70 %.

The coefficient of performance is one of the most important parameters for evaluating the daily productivity of a multistage device, which is defined by the following equation:

$$\eta = \frac{\sum_{i=1}^{N} Ji}{J_1}, \quad (1)$$

where $\sum_{i=1}^{N} Ji$ is the total daily specific productivity of the desalination device per all stages expressed in units of kg/m^{2}day, and J_1 is the daily specific productivity of the one stage desalination device expressed in units of kg/m^{2}day. Process selectivity or retention rate was determined by:

$$K=C1-C2, \quad (2)$$

where $C1$ - is salt concentration in solution, $C2$ - is salt concentration in permeate.

Results and discussions

Specific productivity and coefficient of the thermal efficiency are the main characteristics of the process. Specific productivity is the amount of clean water produced by the unit of surface during a day, kg/m^{2}day. Electrical energy amount produced by the PV panel was also measured.

Experimental investigations were carried out on the desalination device with integrated PV panel (Figure 3) to investigate the power produced from PV panels and to evaluate the fluxes and the quality of drinking water.

Figure 3. Desalination device with integrated PV panel.

The data (the values of the specific productivity of received water and electricity depending on different hours of the day) obtained in testing of the portable four-stage device are shown in figure 4. During the experiments the device reached its operating regime when the seawater in the first stage was heated up. A noticeable amount of distillate appeared after 10:00 am. Later on, the hourly specific productivity achieved its maximal value during the period from 2:00 pm to 4:00 pm. The intensity of radiation varied during a day from 600 – 1000 W/m^2. The temperature and consequently the partial pressure had the main influence on the output. The daily cumulative yield productivity was 9.6 kg/m^{2}day. When sun was in zenith and electric-magnetic rays fell on absorber surface perpendicularly, the power was the largest and equaled to 98 W/m^2. The variations of main hourly characteristics of photovoltaic hybrid desalination device had parabolic shape determined by square equation. The temperature of seawater in the device at 3:00 pm was 67°C, 64°C, 58°C, 51°C respectively at the first, second, third and fourth stages. The performance coefficient, which is defined by the equation (1) for four- stage MD device, was 2.8.

Cumulative values of productivity (J) and electrical energy (P) were also evaluated.

J is the total daily accumulative value of the productivity of the four-stage desalination device expressed in kg/m^{2}day. P is the daily accumulative values of electrical energy produced by PV panels of the device.

P was determined by the sum of products, resulted from the data of multiplying voltmeter and ammeter.

Test results obtained from experiments held on field conditions are presented in figure 5.

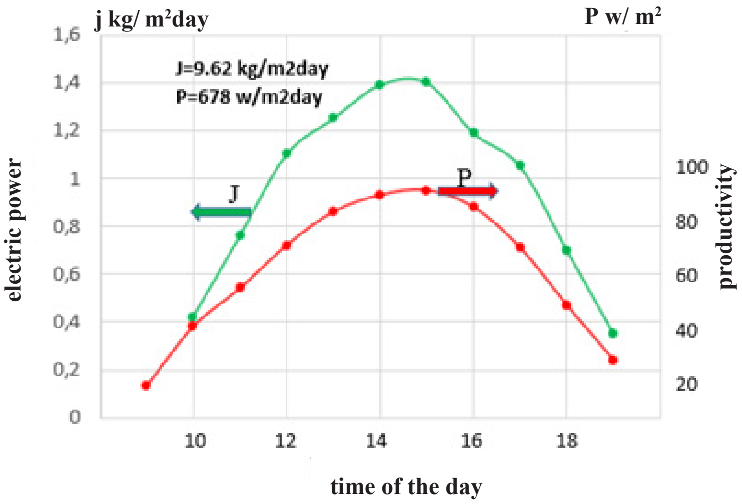

Figure 4. The specific productivity (J) and electric power (P) in four-stage desalination device with integrated PV panel, depending on different hours of the day; the solar radiation is 6.4 kWh/m² day.

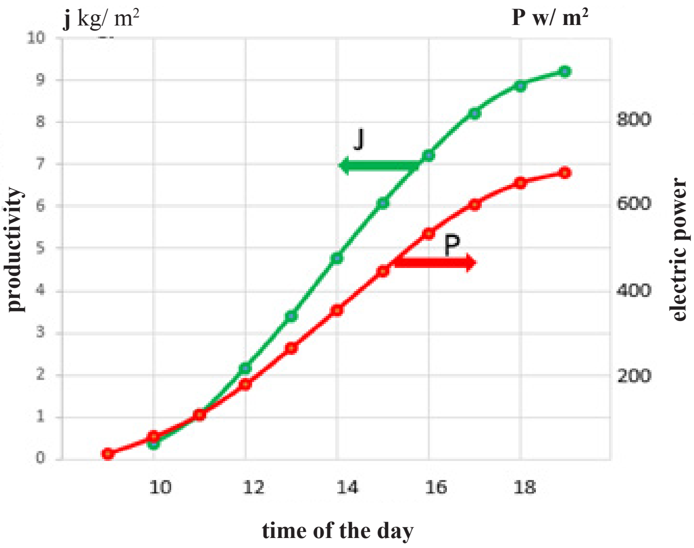

Figure 5. The accumulative values of productivity (J) and electrical energy (P) in four-stage desalination device with integrated PV panel; the solar radiation is 6.2 kWh/m² day.

The experiments were conducted during a typical sunny day, in September, when air maximum temperature raised up to 32°C at 3 pm. During the first three hours we got almost 50 % of the daily specific productivity, because the temperature of saline solution got its maximum value after noon. The daily cumulative yield productivity is 9.2 kg/m² and the accumulative values of electrical energy amounts to 680 W h/m².

Pure water is produced in all series of experiments using the combined MD devices. The TDS is equal to 10 mg/L on average, which indicates that the membrane does not become wet during the desalination process and membrane defects like large size pores do not exist. The retention rate was 99.99 % and nighttime breaks did not influence on the membrane. The electricity produced by photoelectric elements can be used for powering household devices, as well as for other personal needs.

Conclusion

A new device for receiving fresh water and electricity has been designed, which has satisfied the needs of smaller communities and families. Acquiring fresh water and generating electricity are combined into one compact and mobile device. The variation of fresh water productivity and electrical energy during a day was investigated. The water and electricity product deeply depends on the solar radiation. The field experiments show that the system productivity regarding water and electrical energy amounts to about 9.6 kg/m^2 and 680 W h/ m^2 during a day correspondingly. Process selectivity or retention rate was determined and equaled to 99.9 %. The device has a high efficiency since the solar energy absorbed by the absorber is used multiple times with minimal losses. The advantages of MD solar desalination devices consist in their simple robust constructions, small sizes, mobility and independence on fossil fuels and external electricity sources. Thus, the suggested system is a self-supply one that produces fresh water for crop irrigation and is considered to be a source for drinking water and electricity.

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Accepted on 02.12.2019
Reviewed on 21.01.2020