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TÍTULO: Aplicación de la energía solar para eliminar la sal del agua de mar.

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RESUMEN: El uso de tecnologías modernas de edulcorantes incluye una variedad de sistemas térmicos, de membrana y solares en los que el agua salina marina se convierte en agua dulce y potable a través de procesos térmicos o procesos de filtración por membrana; esa es una solución junto con otros procesos de purificación de agua y aguas residuales para responder a la reducción de los recursos hídricos y se ha desarrollado el uso de fuentes alternativas para proporcionar agua a las necesidades de las personas, la industria y la agricultura. En este artículo, se ha intentado revisar el mecanismo general de endulzar el agua de mar usando energía solar, especialmente las técnicas híbridas de membrana y energía solar osmótica y la destilación termodinámica del agua de mar con energía solar.

PALABRAS CLAVES: energía solar, agua de mar, remoción de sal.

TITLE: Application of solar energy to remove salt from seawater.

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ABSTRACT: The use of modern sweetener technologies includes a variety of thermal, membrane and solar systems in which sea saline water is converted into fresh and potable water through thermal processes or membrane filtration processes that is a solution along with other water and wastewater purification processes in responding to reduction of water resources and the use of alternative sources has been developed to provide water for the needs of people, industry and agriculture. In this paper, it has been tried to review the general mechanism of sweetening seawater using solar energy, especially hybrid membrane and osmotic solar energy techniques and thermodynamic distillation of seawater with solar energy.

KEY WORDS: solar energy, seawater, salt removation.

INTRODUCTION.

The request on fresh water is growing progressively and is charming one of the worldwide challenges. The World Health Organization (WHO) guesses that 20% about of the world's population has inadequate access to drinking water (Mohammed Rasool Qtaishat, 2013).

Desalination of seawater is a promising alternative to compensate for the shortage of drinking water. The thermal desalination procedures based on the evaporation of water by the adding of heat that could be provided by the solar energy or by combustion processes, this was one of earliest methods of water treatment and is still a popular treatment solution (Maia, 2019).

Seawater is sweetened with the aim of supplying fresh and drinkable water needed for domestic, industrial and agricultural uses. Of course, due to the high cost of this technology, it is often used to supply people with drinking water.

Seawater is sweetened with the aim of supplying fresh and drinkable water for domestic, industrial and agricultural uses. Of course, due to the high cost of this technology, it is often used to supply drinking water to people. The use of distillation techniques, which is the most common method of sweetening water requires high energy and heat power which usually uses energy of oil and power plants for water filtration that is too costly, and in countries where do not have considerable fossil fuel resources, it is not economically feasible to these methods.

Since seawater desalination is the process consuming a large amount of energy, saving energy to produce freshwater is extremely important in various seawater desalination processes (Zhao, 2019). Under these conditions, water-sweetening technology has been developed with the use of solar energy, which is technologically and economically explainable.

DEVELOPMENT.

Solar water sweetener is a low-cost approach in sweetening seawater and removing salt from it. In fact, solar distillation is a process of producing desalinated water using cost free solar energy.

The method of water purification using solar energy is similar to other distillation methods, with the difference that the energy input to the device is supplied through the energy of the sun's rays and the energy of the environment’s radiation. In this technology, while sun’s ray is passing, seawater or saline water inside the device is heated, its temperature rises and evaporation takes place. Then, the aqueous water starts to distil after colliding with the lower temperature caps of the device, which by collecting this distilled water, the fresh water is obtained (Filippin, 2019).

Different methods have been used to desalinization of seawater with solar energy and removal of salts. One of the simplest and most basic methods is the distillation method.

In the Solar methods, solar energy provides the required heat to evaporation of seawater and its distillation. However, in newer methods, the integration of solar energy with other techniques, including membrane technique has been used. Qtaishat and Banat used membrane distillation system in 2013 along with solar energy for desalinating seawater (Li, 2018).

Membrane distillation (MD) is a hybrid technique that contains membrane-evaporative process, which has been of interest for desalination. MD requires two types of energy, namely, low temperature heat and electricity. Solar collectors and PV panels are mature technologies, which can be coupled to MD procedure. The interest of using solar powered membrane distillation (SPMD) structures for desalination is increasing worldwide due to the MD attractive features.

Hybrid techniques have attracted special attention from scientists in recent years to increase efficiency and reduce the cost of desalinating from the seawater. In 2017, Choi used the barometric vacuum and solar energy hybrid technique for seawater distillation and desalination from it.

In this research, for the further reduction of the SEC, the passive vacuum pipe built on the hydrostatic head was used. This technic was intensive on the freshwater production rates with the height of a passive vacuum pipe. From the theoretical calculations, the freshwater production rate was above 7% of the supplied seawater when the vacuum pipe is 9.8 m and the seawater temperature is up to 80 °C. Their evaporating percentage is very high compared to other conventional thermal type desalination process (Choi, 2017).

In another research, Hakim, et al. (2019) used basin solar energy for development of solar desalination system from seawater. Their research was conducted to develop and improve the current single slope solar still, which is usually made of waste material. The result showed that there was an increment in temperature, as the current solar still gained an extra 5°C after it was improved; this affected the volume of desalinated production, which increased almost up to 150mL from the current solar still. Temperature of process as it increased affected conductivity of water. After the desalination process, the conductivity of seawater contains ions in high value; this value was reduced and only retains pure water characteristics. Heavy metal element concentration in the seawater was reduced after the desalination process before the water was purified to a safer drinking-water standard for each of the element analyzed in this research (Hakim, 2018).

Nikolay Voutchkov (2018) provides an overview of the current status of energy use for seawater desalination, discusses the minimum energy request for production of fresh water and presents key factors that influence the desalination plant energy demand for the site-specific conditions of a given desalination project.

RO system confirmed to yield important energy savings such as: low-recovery plant design; use of divided permeate two-pass RO system configuration; three-center RO system design; and use of high productivity/low energy membrane elements, hybrid RO membrane vessel configurations, large-size high efficiency pumps and pressure-exchanger based energy recovery systems. It is also discussed about emerging desalination technologies with high-energy reduction potential and affords a prediction of the potential impact of future technologies on energy usage for membrane desalination (Voutchkov, 2018).

Use of reverse osmosis technique along with the use of solar energy, have attracted the attention of researchers in recent years. Filippin et al. (2019) investigated the design and economic evaluation of solar-powered hybrid multi-effect and reverse osmosis system for seawater desalination.

Reducing the cost of freshwater has always been a major concern for engineers and researchers in the water desalination industry. A solar powered hybrid multi-effect distillation and reverse osmosis desalination plant (MED + RO) has been design and optimized from an economical point of view in a previous work by the same authors. In the study of Filippin, et. al. (2019), the possibility of coupling the desalination plant with a photovoltaic (PV) solar farm is examined, with the aim of producing electricity at low cost and in a sustainable method.

An accurate mathematical model has been implemented for the PV system of literature. Interestingly, the model can predict the cost of a PV system in terms of cost of capital and electricity cost per kilowatt-hour, according to input data from the sun's radiation, the time of daylight and the technical specifications of a real solar generator. As a result, the PV solar model is combined with the desalination model, which allows it to determine the cost of fresh water per cubic meter.

Data about four locations, namely Isola di Pantelleria (IT), Las Palmas (ES), Abu Dhabi (UAE), and Perth (AUS), have been used to economically test the feasibility of installing the proposed plant, and especially of the PV solar farm.

In the following, the mathematical model provided by this research group is briefly presented.

Data and Methodology.

In the following figure, a simple desalination system is presented based on solar energy.

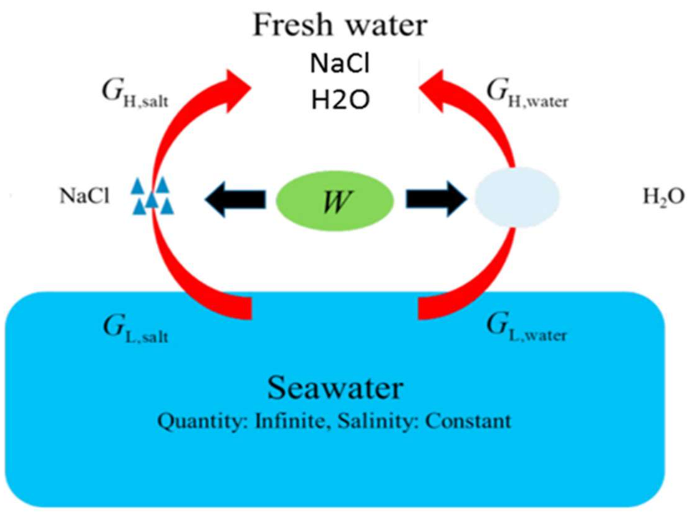

Figure 1: A simple example for ideal desalination process.

Fig. 3 shows an easy schematic diagram which serves to the calculation of minimum energy feeding. Based on the assumptions mentioned in research og Zhao and coworkers, the minimum energy consumption *Wideal* can be calculated by the following equation:

$$W_{\text{ideal}} = G_{\text{H}} - G_{\text{L}} \quad (1)$$

Where, GH, GL are the Gibbs free energy of fresh water and seawater. If seawater and fresh water were considered as ideal solution is consists of NaCl and water. Then, it would be:

$$\begin{aligned} G_{\text{H}} &= G_{\text{H,water}} + G_{\text{H,salt}} \\ G_{\text{L}} &= G_{\text{L,water}} + G_{\text{L,salt}} \end{aligned} \quad (2)$$

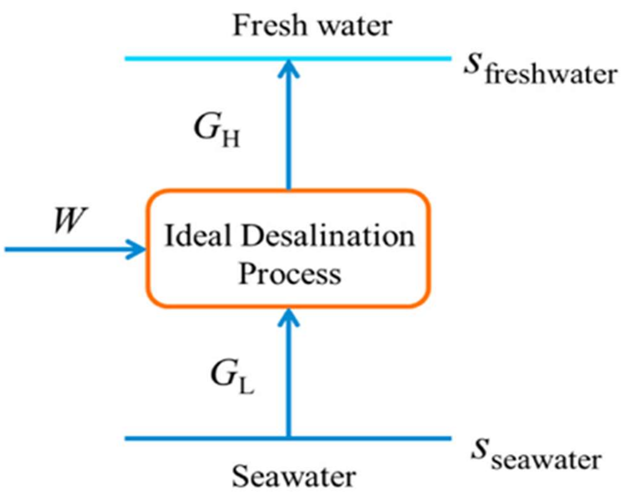

Figure 2- A simplified schematic diagram of modified theoretical model.

According to the literature, the Gibbs free energy of salt and water can be calculated by the following equation (zhao, 2019).

$$\begin{aligned} G_{\text{salt}} &= n_{\text{salt}}\left(g^{0}_{\text{salt}} + RT\ln c_{\text{salt}}\right) \\ G_{\text{water}} &= n_{\text{water}}\left(g^{0}_{\text{water}} + RT\ln\left(\frac{c_{\text{water}}}{c_{\text{water}} + 2c_{\text{salt}}}\right)\right) \end{aligned} \quad (3)$$

By molarity of salt and water, ɲsalt, ɲwater represents the amount of substance of salt and water in per kilogram of fresh water and the above equations we will have:

$$W_{\text{ideal}} = G_{\text{H}} - G_{\text{L}} = n_{\text{water}}\left(RT\ln\left(\frac{c_{\text{fresh,water}}}{c_{\text{fresh,water}} + 2c_{\text{fresh,salt}}} \Big/ \frac{c_{\text{sea,water}}}{c_{\text{sea,water}} + 2c_{\text{sea,salt}}}\right)\right) + n_{\text{salt}}RT\ln\left(c_{\text{fresh,salt}} / c_{\text{sea,salt}}\right) \quad (4)$$

Results.

Potovoltaic (PV) cost mathematical mode.

A mathematical model for the PV system has been implemented from the literature; the model can predict the cost of the PV system in terms of capital cost and electricity cost per kWh considering the input data of solar irradiation, duration of daylight and technical specification of a real solar module. Consequently, the solar PV model has been combined with the desalination model, which enables to estimate the cost of fresh water per cubic meter. Av Schematic of the complete plant (MED + RO + PV) is showed in figure 4 (Filippin, 2019).

The power output of a solar panel in (W) depends on its overall efficiency (η_{tot}), its area (A_{mod}) in (m^2), and solar radiation (G) in (W/ m^2) as depicted in equation

$$P = \eta_{tot} A_{mod} G$$

For evaluation of the overall efficiency losses due to dirt on panel's, surface (ηDIRT), losses due to inverters (ηINV), and losses due to connections (ηCON). The value of ηDIRT depends on the position and frequency of dustings. Almost a number equal to 0.95 should be pretentious a frequent cleaning (Maghami, 2016). Inverters and connections efficiency are assumed 0.98

$$\eta_{tot} = \eta_{MOD} \eta_{DIRT} \eta_{INV} \eta_{CON}$$

Here TC (°C) is cell temperature and SOC is standard operating condition. The module efficiency at TSOC = 25 °C is ηMP, SOC. The temperature coefficient μ (°C-1) has a negative value. Therefore, the module efficiency reductions will be observed for higher cell temperatures (Liu, 2019).

$$\eta_{MOD} = \eta_{MOD.SOC} + \mu(T_C - T_{SOC})$$

A solar panel by Top Sun Energy Ltd has been considered

$$\eta_{MOD,SOC} = \frac{V_{MP,SOC} I_{MP,SOC}}{A_{MOD} G_{SOC}}$$

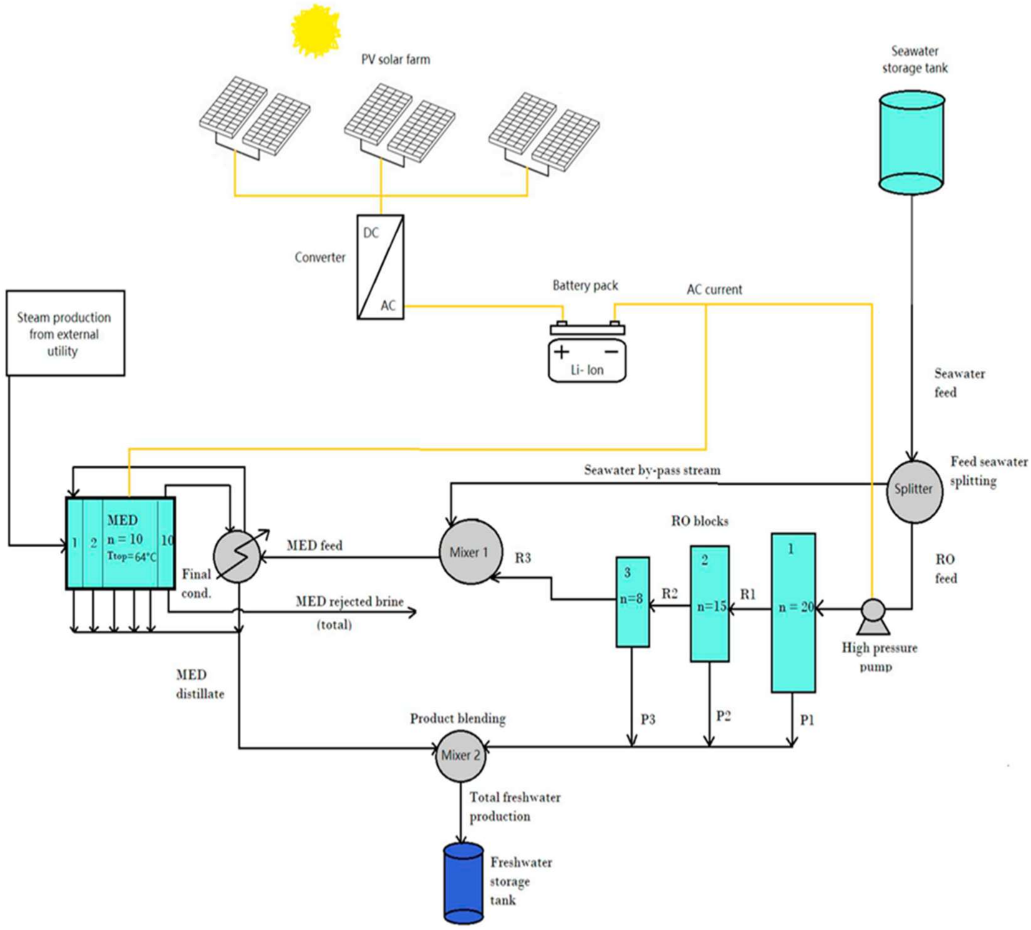

Figure- A Schematic of the complete plant (MED + RO + PV).

Heat losses can be approximated as a linear function of the nominal operating temperature of the panel TC, NOM. With a solar radiation GNOM = 800 W/m2 and ambient temperature Tamb, NOM = 20 °C. TC, NOM is assumed equal to 45 °C. Therefore the module overall efficiency of ηtot, results to be in the range of 15% to 16%, depending on the assumed ambient temperature and solar radiation (Filippin, 2019).

$$P_{tot} = \frac{P_{DES}}{\frac{hours}{24} + \left(1 - \frac{hours}{24}\right)\eta_{CH}\ \eta_{DIS}}$$

In the above equation, the hour is the average time that there is in daily light.

PDES (kWh/day) is the required power by desalination system, ηCH and ηDIS are the charge and discharge efficiency of the batteries.

CONCLUSIONS.

By using thermodynamic decomposition, an equation has been obtained for the minimum energy consumption of the ideal water desalinization process. Minimum energy consumption of desalinating processes increases with the increase of seawater salinity.

The expected cost of electrical energy formed by the proposed PV system is in the order of 0.1 €/kWh, subject on solar radiation and time of daylight.

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