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Solar Seawater Desalination Using a Multi-Stage Multi-Effect Humidification (Meh)-Dehumidification System with Energy Storage

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Abstract: Solar desalination with a multi stage multi-effect humidification (MEH)- dehumidification process with energy storage seems to be an efficient means of utilizing solar energy for production of fresh water from saline or seawater. The principle of desalination in every stage is based on evaporation to and condensation from a closed natural convection air loop in a thermal insulation box. In this paper a three stage multi-effect humidification (MEH)- dehumidification process with energy storage system has been designed, manufactured, installed and out door tested in the Faculty of Engineering, Suez Canal University, Port Said, Egypt. The heat collection part of the system (three flat plate collectors) has been designed to provide the hot water to the desalination chambers and the energy storage at the day hours (12 hours). While the energy storage provides the desalination chamber by the required heat at part of the night hours (3 hours). The experimental test results showed that, the increase of seawater mass flow rate through the system from 0.1 liter/s to 0.13 liter/s increases the productivity of the system by 10 %. It can be seen from the results also that the use of energy storage increases the productivity by 13.5%. The productivity of the system is about three times the productivity of the conventional solar still. Main advantages of the system are the low electric energy consumption (only for pumping the brine), low maintenance and no operation requirements. The self- controlling free convection air loop supports the first rate partload performance of the system, which is important for the solar applications.

Key words: Missing

INTRODUCTION

Drinking water of acceptable quality has become a scarce commodity. In many places of the world only brackish or polluted water is available. This leads to an increasing interest in new desalination technologies. The standard methods like Multi-stage-flash-Evaporation and Multi-Effect-Evaporation, Vapor Compression and reverse Osmosis are reliable in the capacity range of some 100 to 500.000 m3 per day fresh water production [1]. They are not used in regions with low infrastructure and for the supply of decentralized regions because of their permanent maintenance and electric energy supply. Here the use of small-scale, solar desalination systems are desirable and make economic sense. Recent investigations have focused on the use of renewable energy to provide the required power for the desalination processes. The most popular renewable energy source being solar energy [2]. Solar desalination represents one of the oldest techniques and is successfully used for the production of fresh water from brackish/saline water, in many parts of the world. The solar desalination process offers the advantage of doing practically no ecological damage and creating minimum energy cost. In locations with abundant sunshine, such as Egypt, solar desalination is a potentially viable option, especially for small-scale plants in remote locations [3]. Solar water desalination plants use collected solar energy for direct heating and evaporating salty water to obtain fresh water [4]. In other cases, solar energy has been used to heat seawater and later to inject the warm water into air to humidify it. The subsequent cooling of the humid air delivers the needed water of free of salt [5-10]. It has been shown that the humidification-dehumidification process could be an efficient and economical method for solar desalination, especially for small quantities in remote areas [11]. In this paper a three stages multi-effect humidification-dehumidification (MEH) solar desalination chambers connected in series coupled with three flat plate solar collector and an energy storage have been designed,

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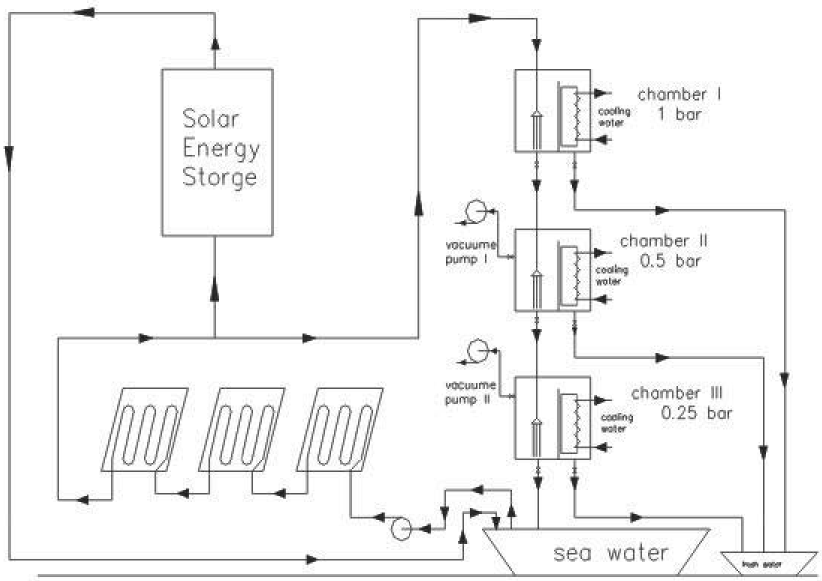

Fig. 1: Day Time Mode: Collectors heat is fed to first desalination chamber and solar energy storage

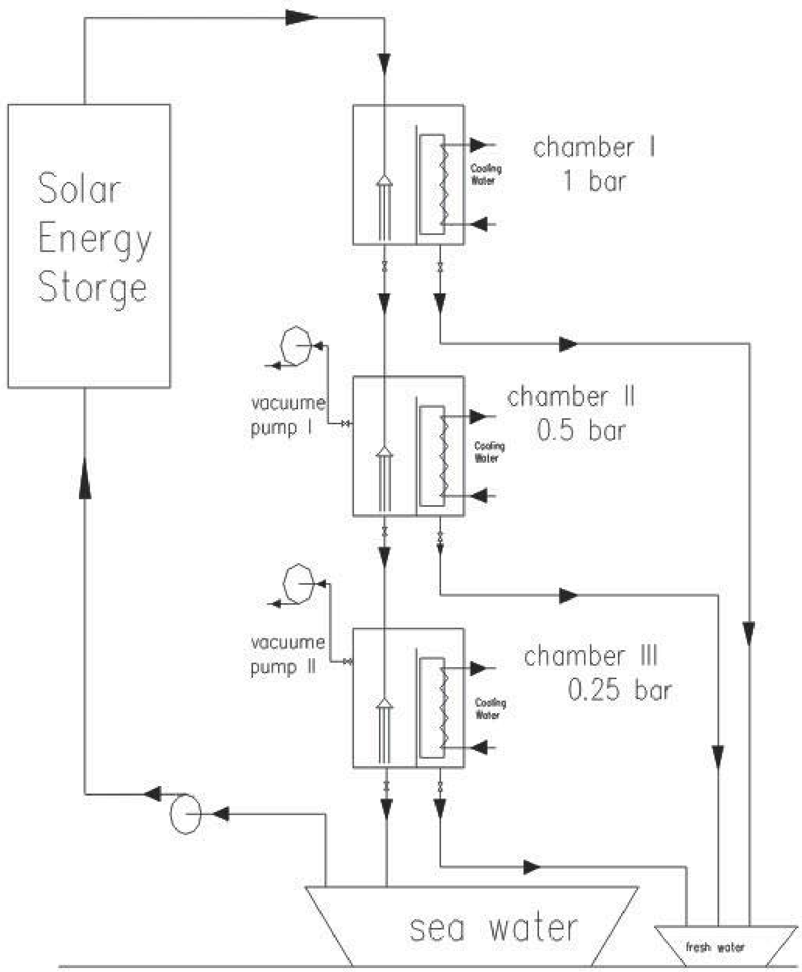

Fig. 2: Night Time Mode: solar energy storage heat is fed to first desalination chamber

installed and outdoor tested in the faculty of Engineering, Suez Canal University, Port Said, Egypt. The tests have been carried out for Port Said climatic conditions (31°17' N latitude, 32°12' E longitude). The system uses a three flat plate solar collector connected in series as a heat source. Every desalination chamber consists of humidifier (evaporator) and dehumidifier (condenser with fins) towers. The circulation of air in the two towers was obtained by natural convection. In this work an experimental investigation on the proposed solar distillation system had been carried out. The study includes design, construction and testing of the system (Figs. 1&2).

THE PRENCIPLE OF DESALINATION CHAMBER

The main idea of the multi-effect humidification (MEH)-dehumidification solar desalination chamber based on the evaporation of water and the condensation of steam to and from humid air. The humid air circulation driven by natural convection between evaporator tower (humidifier) and condenser tower (dehumidifier) as shown in Figs. 4&5. Evaporator and condenser are located in the same insulated box. The heated seawater from solar collectors is distributed onto the evaporator tower through a vertically hanging sprayer and is slowly trickling downwards. The condenser unit is located opposite to the evaporator. Here the saturated air condenses on a single tube copper coil with fins as shown in Fig. 6. Water with ambient temperature was used as a coolant for the condenser. The distillate runs down to a collecting tank.

TEST RIG DESCRIPTION

A schematic diagrams of the three stages multi-effect humidification (MEH)-dehumidification solar desalination system with energy storage in day time mode and night mode are shown in Figs. 1&2. Also a photo of the test rig is shown in Fig. 3. Every stage consists of a desalination chamber (0.5m x 0.5m x 0.5m) made of galvanized iron sheet (0.003 m thick) formed by bending and assembled by soldering. It is divided into two parts, evaporator tower (humidifier) and condenser tower with fins (dehumidifier) as shown in Figs. 4&5. The three stages are connected together in series. The heated seawater from the three stages solar collectors (connected together in series to increase the total temperature rise) is divided into two branches in morning mode. The first branch distributed onto the evaporator tower of the first chamber through a vertically hanging sprayer at the middle of the chamber [3] and is slowly trickling downwards. The second branch

Fig. 3: Photo of the test rig

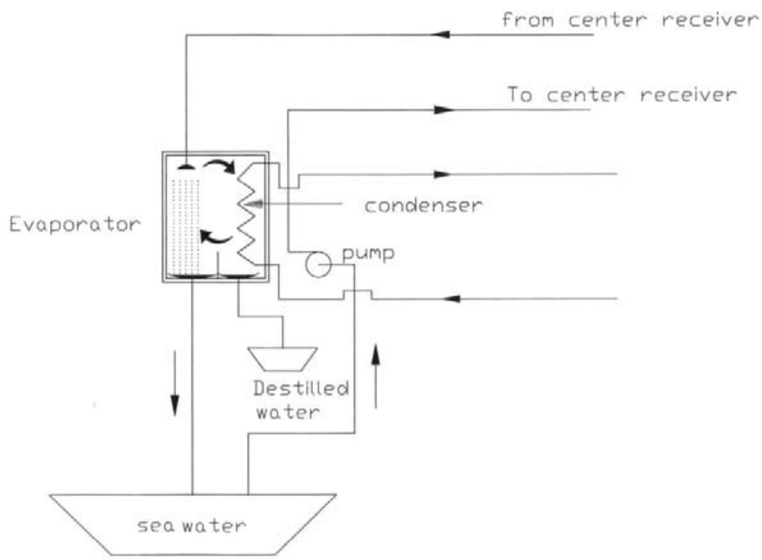

Fig. 4: Schematic diagram of desalination chamber

Fig. 5: Photo of desalination chamber

flows to the energy storage to store heat in it and then flows to the sea water tank. The condenser unit is located opposite to the evaporator. The condenser consists of a 0.025 m single tube copper coil with four thin copper fins along it to enhance the heat transfer coefficient. The fresh water from the condenser is collected and measured every hour in the fresh water tank. The sea water drain from the first chamber flows to the second chamber which has the same design and so on. The three identical insulated desalination chambers are connected together in series and they are coupled with three (1m x 1m) solar collectors by means of a pump to transport the heat from the solar collectors to the brine in a 0.025 m single tube copper coil. The three solar collectors connected together in series to increase the total temperature rise. A PVC pipe is used for the supply of seawater. The whole chambers and solar collectors are almost vapor-tight; silicon rubber is used as a sealant because it remains elastic for quite long time. The solar collector used in seawater heating is an insulated (1m x 1m) waterproof box containing dark absorber plate under a transparent cover (0.003 m thick ordinary window glass). The box is made of galvanized iron sheet (0.003 m thick) formed by bending and assembled by soldering. The dark absorber plate(galvanized iron sheet 0.003 m thick.) catch up heat from sunlight that passes through the cover and then gives the heat up to the sea water flowing in a copper single tube coil past the absorber surface. The solar energy storage is an insulated tank (0.5m x 0.5m x 1.0m) filled with heavy oil and black gravel. The tank is made of galvanized iron sheet (0.003 m thick) formed by bending and assembled by soldering. In night time mode the solar energy storage works as a heat source for the system instead of the three stage solar collectors in morning mode as show in Fig. 2. Experiments have been carried out outdoors during summer of 2004. The global solar radiation on a horizontal surface and on the solar collectors is measured using a silicon cell pyranometer model (3120). wind speed is also measured. Calibrated NiCr-Ni thermocouples are used to measure the temperatures at different points in the desalination chamber, solar collectors and energy storage tank. The ambient temperature has been also measured.

RESULTS AND DISCUSSION

Experimental tests were carried out in successive days during July 2004 to ensure the same climatic conditions for all tests. The results obtained are summarized in the following figures. Fig. 6 shows the hourly variation of wind speed. Fig. 7 shows typical measurements of solar radiation intensity on horizontal surface. The hourly temperatures variation of solar collector absorber and glass cover are presented in Fig. 8. It is clear from the curve that the maximum temperatures obtained around noon. Fig. 9 presents the hourly temperature variation at the input of the first evaporator and ambient. Fig. 10 shows the hourly accumulative productivity for the system without energy storage (msw=0.08 lit/s). Fig. 11 shows the hourly accumulative productivity for the system without energy storage (msw=0.1 lit/s). It can be seen from the above two

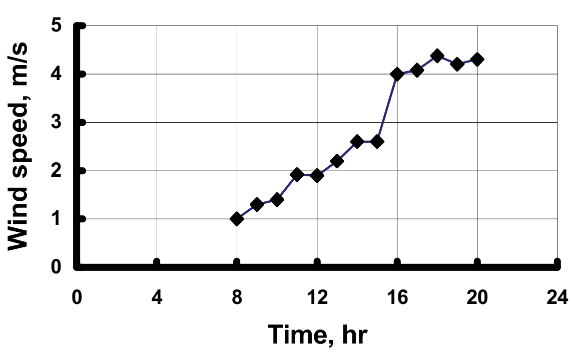

Fig. 6: Wind speed

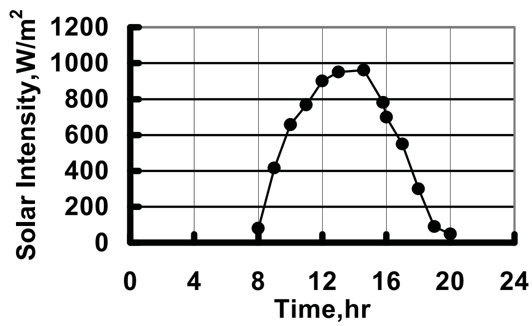

Fig. 7: Typical measurements of solar radiation intensity on horizontal surface

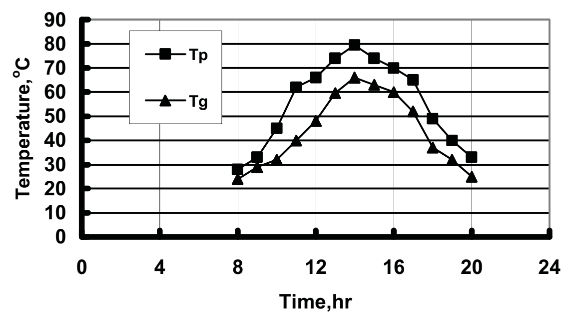

Fig. 8: The hourly temperatures variation of solar collector absorber and glass cover

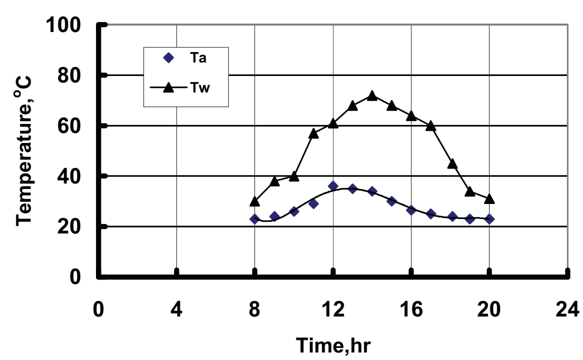

Fig. 9: The hourly temperature variation at the input of the first evaporator and ambient

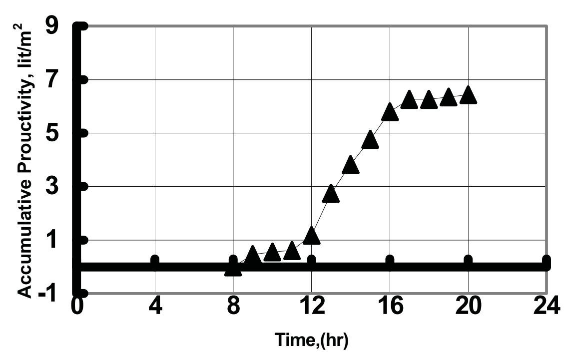

Fig. 10: The hourly accumulative productivity for the system without energy storage (msw=0.08 lit/s)

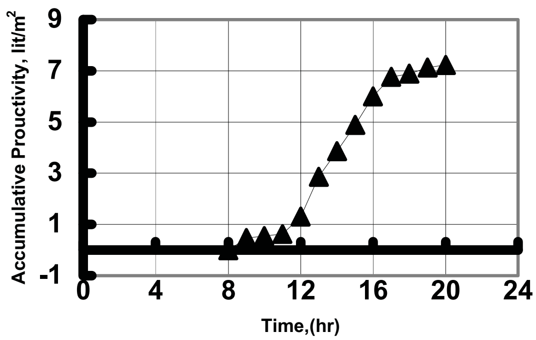

Fig. 11: The hourly accumulative productivity for the system without energy storage (msw=0.1 lit/s)

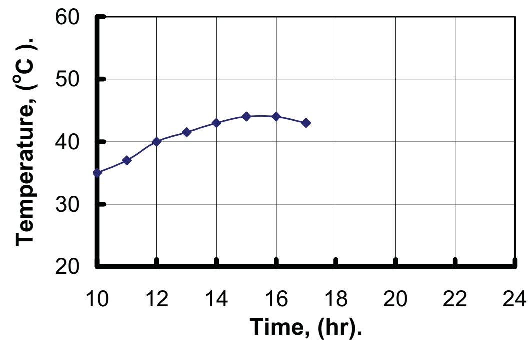

Fig. 14: Hourly variation of salt water temperature at energy storage outlet

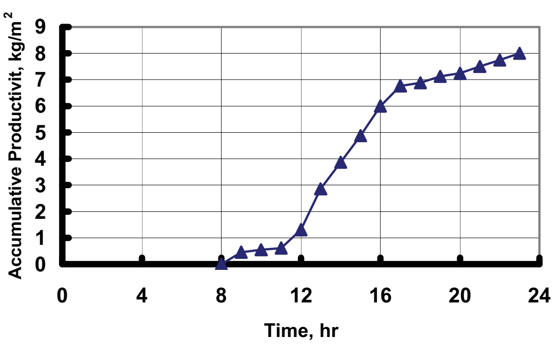

Fig. 12: The hourly accumulative productivity of the system with energy storage (msw=0.1 lit/s)

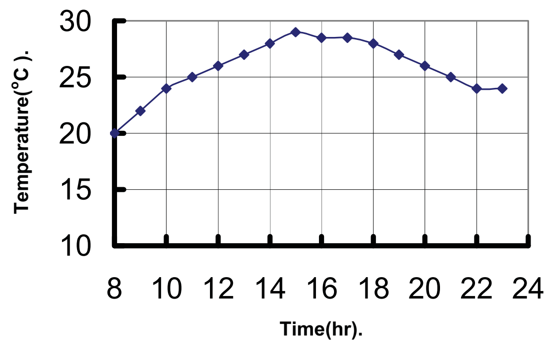

Fig. 15: Hourly variation of condenser cooling water inlet temperature

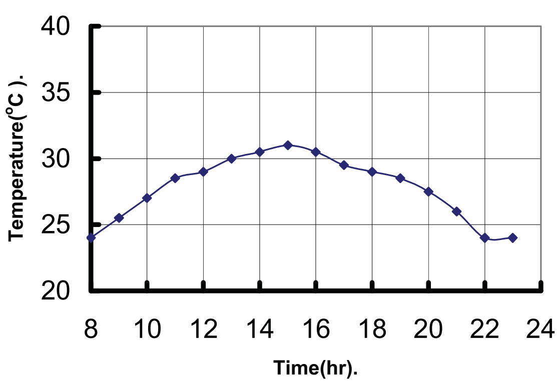

Fig. 13: Hourly variation of distilled water temperature for the system with energy storage (msw=0.1 lit/s)

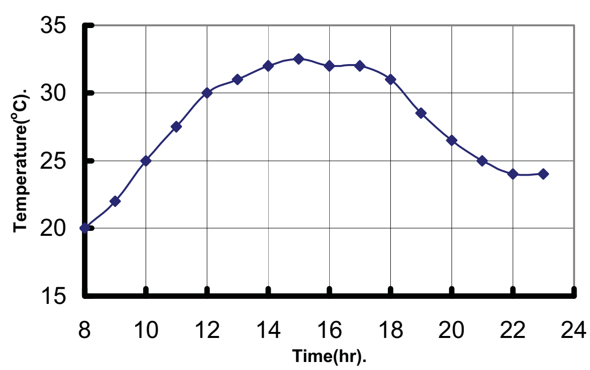

Fig. 16: Hourly variation of condenser cooling water outlet temperature

curves that the increase of sea water mass flow rate in the system from 0.08 lit/s to 0.10 lit/s increases the daily productivity by 12%. The hourly accumulative productivity of the system with energy storage (msw=0.1 lit/s) is presented in Fig. 12. It is clear that from Figures 11&12 the use of energy storage increases the daily productivity by 10%. Fig. 13 shows the hourly variation of distilled water temperature for the system with energy storage (msw=0.1 lit/s).

The hourly variation of salt water temperature at energy storage outlet is presented in Fig. 14. It can be seen from the above curve that the a part of the heated sea water from the third solar collector in morning mode.

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