Solar Thermal Desalination Systems with Multi-layer Heat Recovery

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1. Introduction

During the thermal desalination of sea water, the evaporation process has a high energy demand. Around 2294 kJ/kg are required to produce just one litre of distilled water. If solar energy is used to power this process a large area is required. Due to the extensive installation required this involves high costs. To make such an idea economically viable, energy-saving desalination technology must be used. An improvement in energy efficiency is possible because of the recovery of the evaporation enthalpy in a multi-layer arrangement (see Figure 1). The main benefit of the development described here is that it is easy to use and avoids the use of moving components such as pumps and electronic controls. The unit also does not need an electricity supply and can be operated by users with little technical skills. This system should provide an economically attractive alternative to the technically demanding desalination systems commercially available, while still producing between 50 and 5000 litres of drinking water per day.
The basis of the multi-layer desalination plant was researched as part of an AIF Research Project (FKZ:1708499). Using a seven-layer unit, an energy recovery level of GOR= 2,8 was achieved with a production rate of 8 kg/m²h.

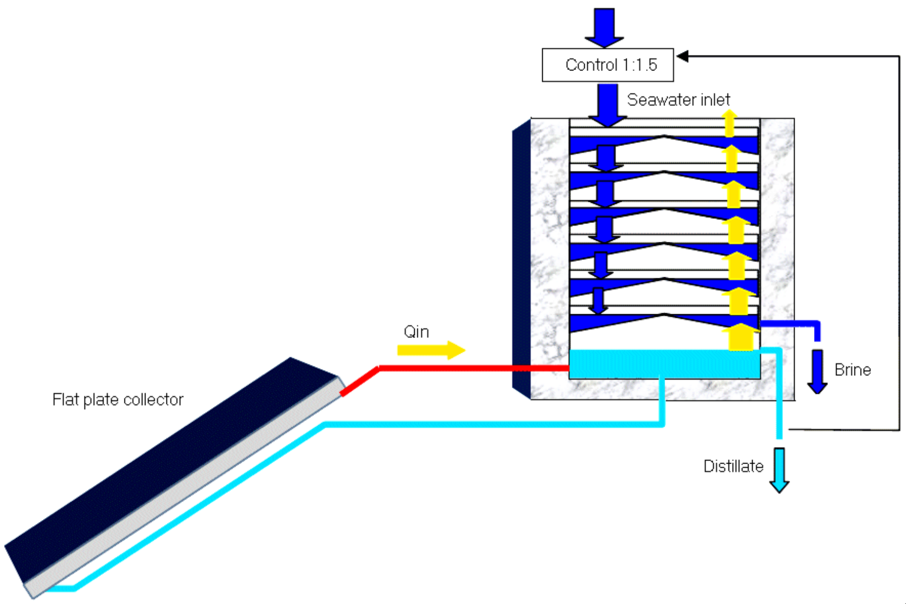

Fig. 1: Schematic of a solar multi-layer desalination unit

2. The solar desalination systems

In a project supported by Greenpeace International, 3 types of solar desalination plants using multi-layer heat recovery were investigated:

- 4 m^2 flat plate collector with a 1 m^2 evaporation surface
- 2.4 m^2 parabolic reflector with a 0.66 m^2 evaporation surface
- 2 m^2 evacuated tube collectors with a 1 m^2 evaporation surface

Fig. 2: Greenhouse-type still in comparison with desalination units with flat plate collector and parabolic reflector

Figure 2 shows a diagram of the desalination module with the collector. The lowest level of the unit serves as the first level of the desalination tower and as a water tank to catch the desalinated water. The heat produced by the surface collector is introduced here. The condensate runs directly through the collectors acting as a heat transfer medium. As the collectors are situated under the condensation unit, the circulation through the solar collector is driven by normal thermal convection. The two collectors with 2 m^2 of surface area each have their own circulation system. An additional reflector at the top and bottom of the collectors enlarges the surface of the aperture. Figure 3 shows the results of measurements taken using this system on a summer's day. The temperature of the unit and the upper level is shown, as well as the production of desalinated water and the irradiation over a period of 24 hours. The ratio of condensed water to salt water was set to around 1:1.8 . The unit produced a total of 44 kg of desalinated water over the 24 hours. The total amount of solar energy collected in one day stands at around 7.23 kWh/ m^2d. This means that the effectiveness of the solar energy in relation to the energy actually used ($Q= M_{dest}*h$) can be calculated to be at 98%. A simple greenhouse-type distillation unit was set up as a reference, and produced in the same time frame a total of 4.0 litres per square meter aperture. When the two units are compared, it can be seen that it is possible to obtain a production which is 2.75 times more efficient with the same energy input than in the simple system. Alternative system designs, which use evacuated tube collectors and parabolic reflectors are depicted in Figures 4 and 5.

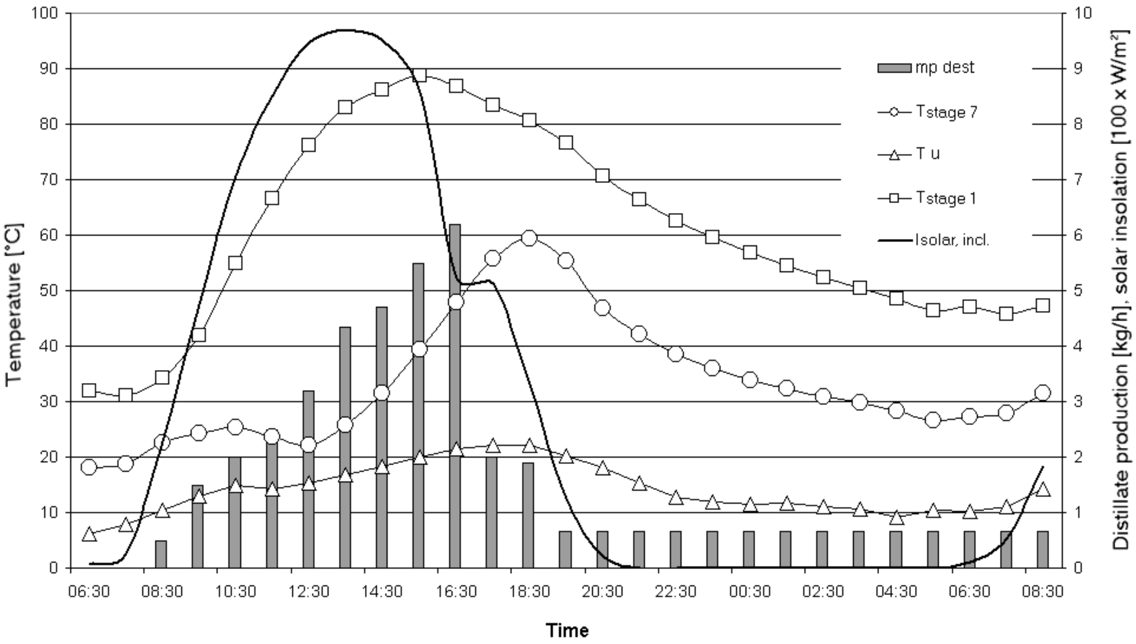

Fig. 3: Measured data of a flat plate desalination system over a time period of 24 hours

The parabolic reflector model is always placed in an east-west alignment. The Aperture width is 1,5 m. The reflector has to be tracked over the day to keep the focal line always on the receiver. This must be done with as little effort as possible. For that reason the focal point is allowed to move over a width of 20 cm over the absorber surface during the course of the day. This means that, depending on the geographical latitude, only one daily adjustment is required to keep the focal line in position. The absorber also holds the salt water and so serves as the first stage of the desalination tower. Heat is delivered directly and without delay to the system. In windy conditions, however, large heat losses occur as the absorber is only protected by a shallow cavity. Additionally, during night-time intense heat losses occur at the bottom surface and cool down the system fast. In particularly windy areas, the idea of protecting the absorber by a glass cover may be considered. But due to reflection on the glass, energy losses have to be taken into account. When the sun's rays are at a low angle as many units as possible must be connected together to minimise the loss of concentrated radiation at the edges of the parabolic reflector (see Figure 4). Measurement results have shown that on the one hand the parabolic reflector system heats up very fast due to the little heat capacity and on the other hand loses heat as fast again in the night time. Overall, with a reflector aperture of 2,4 m² the same daily output can be achieved as with a flat plate collector with 4 m². Since a concentrating system uses only direct insolation, it depends on the climatic region if a concentrating system or a flat plate system is to be preferred.

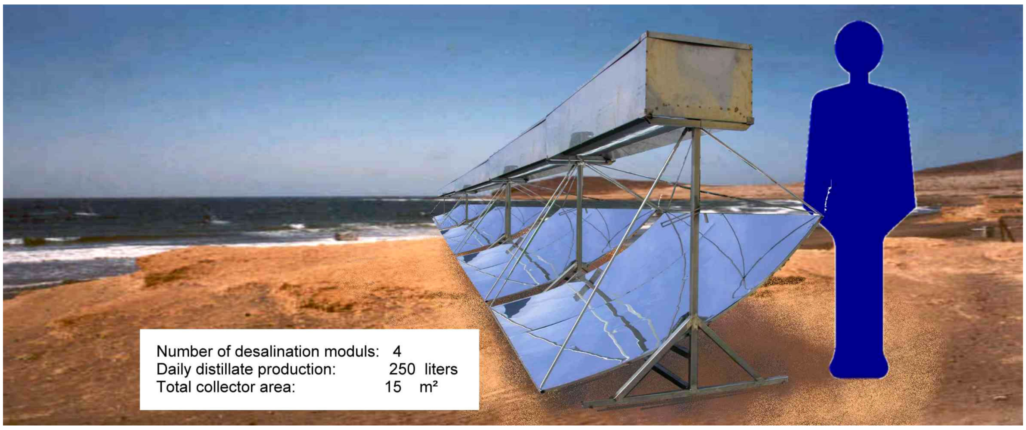

Fig. 4: Parabolic reflector model

Another solution is the utilisation of evacuated tube collectors. For a prototype 20 Sydney –type tubes were connected directly to the evaporation stage. The distillate flows driven by natural convection, directly through the tubes, carrying the heat to the evaporator. Evacuated tube collectors are currently available at low cost from Chinese manufacturers and offer an interesting economical alternative. These collectors are very insensitive to wind and work at a high efficiency even at temperatures of 100°C. However, it must be noted that with large spacing between the tubes the effective area is significantly reduced and only a limited performance is achieved. Regarding the complete collector area the optical efficiency amounts to only 40% for a system without CPC.

Fig. 5: Evacuated tube collector model

3. Simulation

The dynamic simulations were carried out using Matlab/Simulink. The implementation of the thermodynamic model of a plant with 7 stages is depicted in the figure below. The model of a stage with all heat flows is collated to a single block, including thermal inertia. For an easier usage the evaporation area, quality of insulation, spacing between evaporator and condenser and the water volumes can be defined in a menu mask. Supplied heat energy, i.e. from a solar collector and ambient data are put in on the left. A scaling factor defines the quantity of brine entering the system.

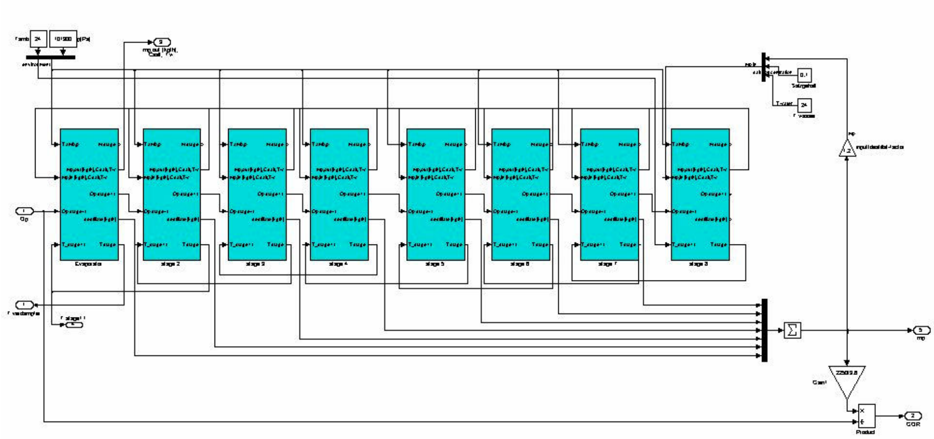

Fig. 6: 7-stage system as simulation model

The model had to be validated with measurement data from the unit in connection with a flat plate collector. The comparison of the simulation and the measured data can be seen in diagram figure 7. The accordance of simulated and measured data is very good. Differences in temperatures are mainly due to the uneven temperature distribution in the stages. So it occurs that a sensor is nearer to the cold seawater input and so measures a lower temperature.

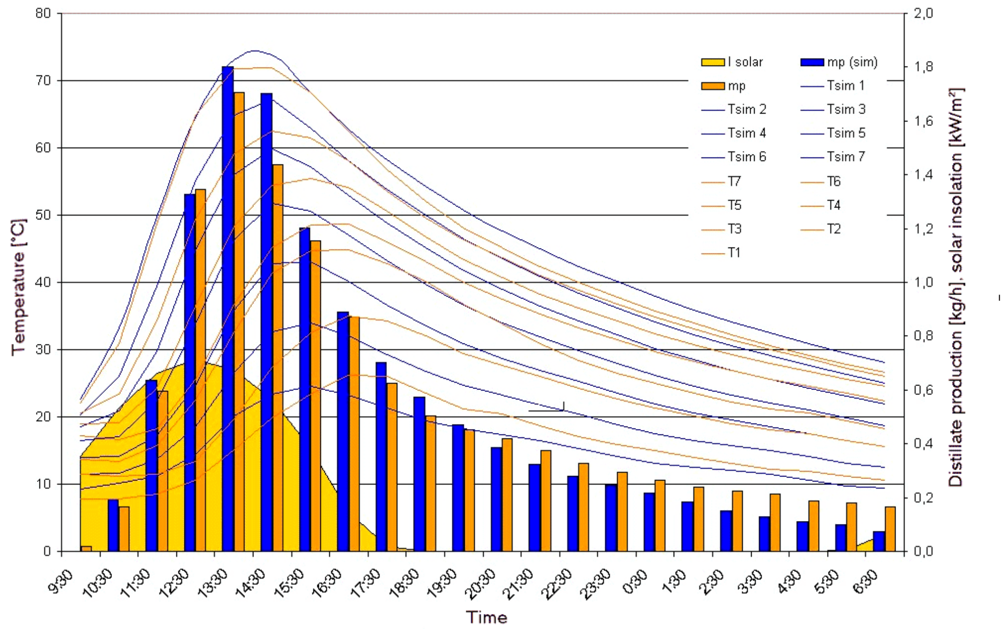

Fig. 7: Comparison of measured and simulated data

With the help of a validated complete system, it is possible to predict the performance of the unit in other climatic regions. As an initial prognosis, the simulation was performed using weather data from Sidi Barrani on the Egyptian Mediterranean coast. The average daily production over a period of one year of a 1 m² model with a 4 m² flat plate collector is shown in Figure 8. The daily production is seen to be between 20 and 60 kg/d, depending on the time of year. The average yearly production achieved by the unit reached 47 kg/d.

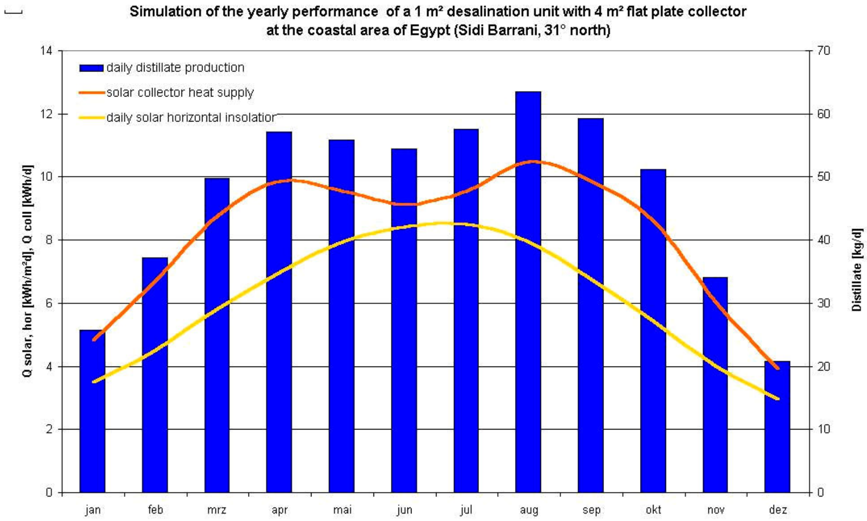

Fig. 8: Simulated yield per day in the course of a year

In order to reduce the energy requirements even further, an additional system to recover the heat from the condensate and the discharged salt water, especially designed for solar thermal desalination units, is now being investigated with the financial support of RWE Aqua (Thames Water). Initial attempts have already shown very promising results.