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SIMULATION OF FRESH WATER PRODUCTION USING A HUMIDIFICATION-DEHUMIDIFICATION SEAWATER GREENHOUSE

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ABSTRACT

A thermodynamic simulation study was performed on the influence of greenhouse-related parameters on a desalination process that combines fresh water production using humidification-dehumidification with the growth of crops in a greenhouse system. With the system under study, surface seawater trickles down a porous front wall evaporator through which air is drawn into the greenhouse. The saturated air passes through a condenser, which is cooled using cold deep seawater or cool seawater coming out of the evaporators. Thermodynamic modeling of the Seawater Greenhouse system in our laboratory has shown that the dimension of the greenhouse had the greatest overall effect on the water production and energy consumption. A wide shallow greenhouse, 200 m wide by 50 m deep gave 125 $m^3.d^{-1}$ of fresh water. This was greater than a factor of two compared to the worst-case scenario with the same area (50 m wide by 200 m deep), which gave 58 $m^3.d^{-1}$. Low power consumption went hand-in-hand with high efficiency. The wide shallow greenhouse consumed 1.16 $kW.h.m^{-3}$, while the narrow deep structure consumed 5.02 $kW.h.m^{-3}$. The benefits of the development of the Seawater Greenhouse for arid regions were discussed.

INTRODUCTION

Solar desalination methods are well suited for the arid and sunny regions of the world as in the Arabian Peninsula [1-3]. A variety of solar desalination devices have been developed. One of the more successful examples is the multiple-effect still. Latent heat of condensation is recovered, in two or more stages (generally referred to as multi-effects), so as to increase production of distillate water and improve system efficiency. It has become apparent that a key feature in improving overall thermal efficiency is the need to gain a better understanding of the thermodynamics behind the multiple use of the latent heat of condensation within a multi-effect humidification-dehumidification solar still [4]. In addition, while a system may be technically very efficient it may not be economic (i.e., the cost of water production may be too high) [5]. Therefore, both efficiency and economics need to be considered when choosing a solar desalination system. There is also a growing realization in arid and non-arid countries that the long-term solution to a shortage of potable water lies in a coordinated approach involving water management, purification, and conservation [6].

A recent example of a humidification-dehumidification system is a pilot plant built at Kuwait University [7]. The system consisted of a salt gradient solar pond, which was used to load the air with humidity. Fresh water was collected by cooling the air in a dehumidifying column, producing 9.8 $m^3 \cdot d^{-1}$ distillate. An air-dehumidification method suitable for coastal regions was also described by Khalid [8]. In a similar study, a closed-air cycle humidification-dehumidification process was used by Al-Hallaj et al. [4] for water desalination. Paton and Davis [9] used the humidification-dehumidification method in a greenhouse-type structure for desalination and for crop growth (Figure 1). Their Seawater-Greenhouse, produced fresh water and crop cultivation in one unit. It was suitable for arid regions that have seawater nearby. The temperature differences between the solid surfaces heated by the sun and cold water drawn from below the sea surface was the driving force in the system. The greenhouse acted as a solar still providing a controlled environment inside the greenhouse. A thermodynamic model was employed in analysis of water production and energy consumption.

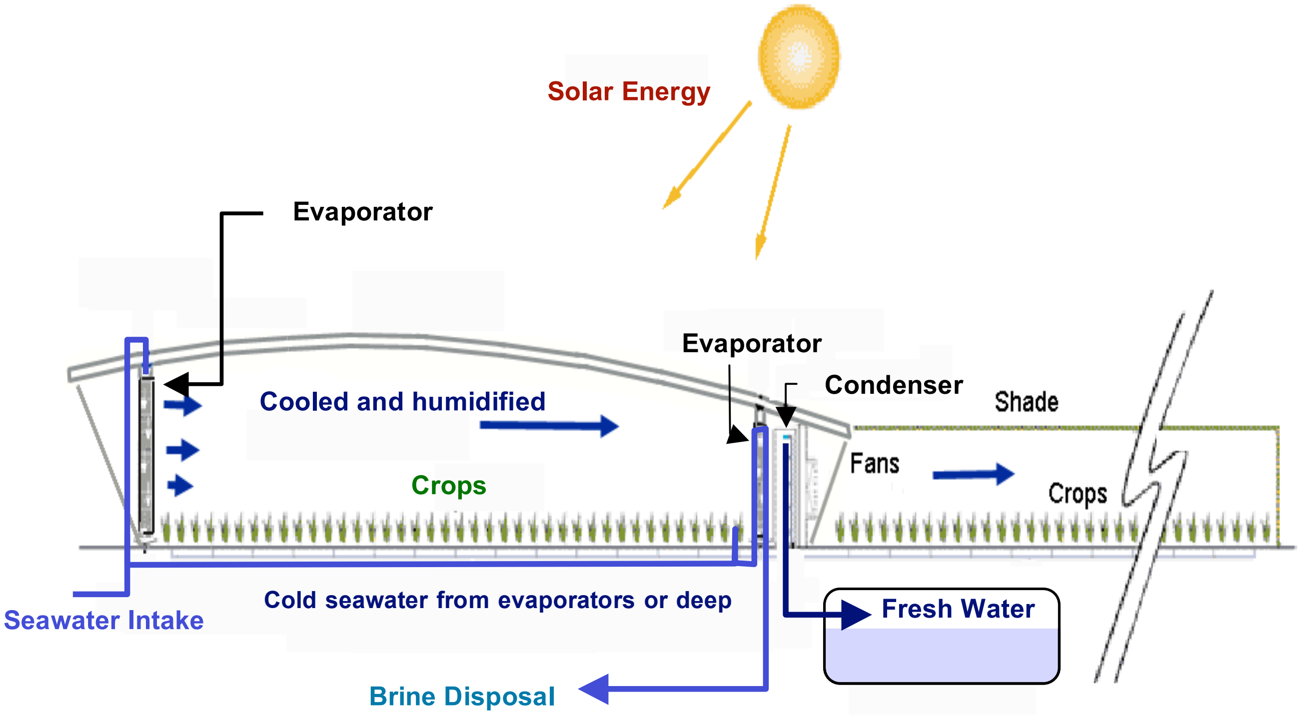

Figure 1 Seawater Greenhouse [9] : 1. Surface seawater trickles down the front wall evaporator, through which air is drawn into the Greenhouse. Dust, salt spray, pollen and insects are trapped and filtered out leaving the air pure, humidified and cool; 2. Sunlight is selectively filtered by the roof elements to remove radiation that does not contribute to photosynthesis. This helps to keep the Greenhouse cool whilst allowing the crops to grow in high light conditions; 3. Air passes through a second seawater evaporator and is further humidified to saturation point; 4. Saturated air passes through the condenser, which is cooled using cold deep-sea water. Pure distilled water condenses and is piped to storage; 5. Fans draw the air through the Greenhouse and into the shade house area.

The primary aim of our study was to determine the influence of greenhouse-related parameters on a desalination process that combines fresh water production using humidification-dehumidification with the growth of crops in a greenhouse system. A thermodynamic model was used based on heat and mass balances.

METHODOLOGY

Thermodynamic Simulation Model: A software program developed by LightWorks Limited, England was used to model thermodynamic analysis of the humidification/dehumidification Seawater Greenhouse system. The computer program consisted of several modules: Seapipe, Airflow, Evaporator 1, Roof, Planting Area, Evaporator 2, Condenser (air/water heat exchanger). Weather data for the year 1995 obtained from the Meteorological Office situated at Muscat were used. The software needs a weather data file and a bathymetric (seawater temperature) file. These are specific to a location. The file contained transient data on solar radiation on a horizontal surface, dry bulb temperature and relative humidity of air, wind speed and wind direction. The bathymetric file contained temperature of the seawater at distance along the sea bed from the coast. The software program predicts the inside air conditions and water production for a given configuration/dimension of the greenhouse, and weather and bathymetric data. The program allows many parameters to be varied. These variables can be grouped into following categories: Greenhouse (i.e. dimension of the greenhouse, and its orientation, roof transparency of each layer, height of front and rear evaporative pads, height of the planting area, condenser); Seawater pipe; Air exchange.

Simulation runs: In the present analysis three parameters i.e. dimension of the greenhouse, rooftransparency and height of the front evaporator were taken as variables. These parameters were varied as follows: Dimensions of Greenhouse (width x length): Area was kept constant at 10^4 m^2; 50 x 200, 80 x 125, 100 x 100, 125 x 80 and 200m x 50m; Roof Transparency 0.63 x 0.63 and 0.77 x 0.77; Height of the Front Evaporator 3 and 4m . The parameters kept constant were: Height of Planting Area = 4m; Height of the Rear Evaporator = 2m; Height of the Condenser = 2m, Orientation of Greenhouse = 40^o N; Seawater pipe diameter = 0.9m, length = 5000m; Volumetric flow = $0.1m^3/s$; Pit depth = -3m, height = 7.5m, wall thickness = 0.1m; Air change = 0.15 (fraction)/min; Fin spacing = 0.0025m and depth = 0.1506m

RESULTS AND DISCUSSION

Simulation studies of the Seawater Greenhouse system showed that the dimensions of the greenhouse (i.e. width to length ratio) had the greatest overall effect on water production and energy consumption, Figures 2 and 3, respectively. The overall water production rate increased from 65 to 100 $m^3.d^{-1}$ when the width to length ratio increased from 0.25 to 4.00. Similarly the overall energy consumption rate decreased from 4.0 to 1.4 kW.h. m^{-3} when the width to length ratio increased from 0.25 to 4.00.

A 5 x 2 x 3 full factorial design was employed with five dimensions (width and length) of greenhouse, two roof transparencies and three heights of the front evaporator. A total of thirty simulation runs were carried out with one year of weather data. The water production and power consumption data were analyzed using Statistical Analysis System (SAS) program. Analysis of variance (ANOVA) procedure was used to detect the significance of the dimension of the *Greenhouse*, transparency of roof materials and height of the front evaporator.

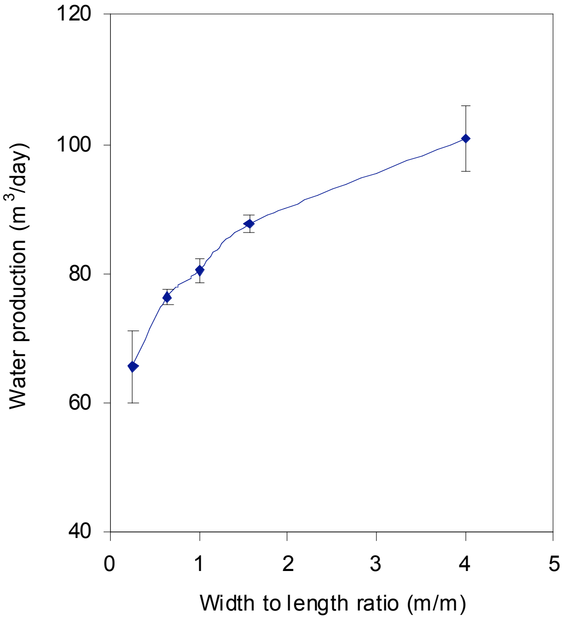

Figure 2. Overall effect of width to length ratio on water production rate.

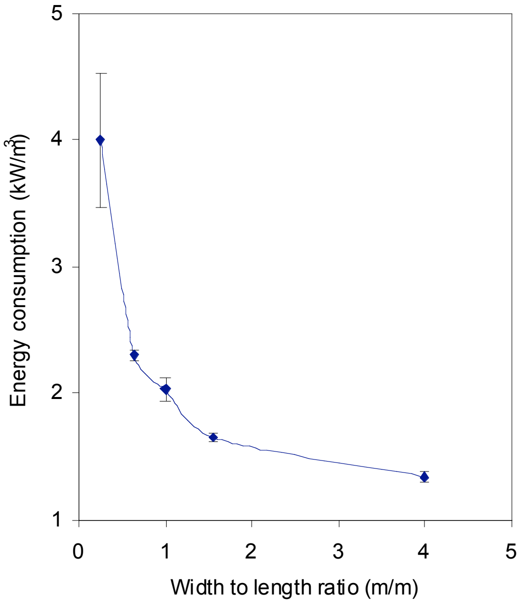

Figure 3. Overall effect of width to length ratio on energy consumption.

The results showed that the overall effects of roof transparency and evaporator height on water production were not significant. It was possible for a wide shallow greenhouse, 200 m wide by 50 m deep with an evaporator height of 2 m, to give 125 $m^3.d^{-1}$ of fresh water. This was greater than a factor of two compared to the worst-case scenario with the same overall planting area

(50 m wide by 200 m deep) and same evaporator height, which gave 58 $m^3.d^{-1}$. For the same specific cases, low power consumption went hand-in-hand with high efficiency. The wide shallow greenhouse consumed 1.16 kW.h. m^{-3}, while the narrow deep structure consumed 5.02 kW.h. m^{-3} . While these results suggest that a wide shallow greenhouse is technically most

efficient, it is important to remember that the model does not take into account the increase in capital and operating costs of the evaporator and condenser for the wider greenhouse.

In closing, there are several benefits for the development of the humidification-dehumidification Seawater Greenhouse system in arid regions such as the Arabian Gulf. It provides for additional water supplies for other purposes such as the development of environmental projects. It allows for the opportunity to develop a high value agricultural sector that is sustainable in the long term and immune to climatic variations. It also gives new market options for import substitution and export development.

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