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Study on parameters effective on the performance of a humidification-dehumidification seawater greenhouse using support vector regression

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ABSTRACT

A Seawater greenhouse is a desalination plant that, using solar energy and seawater, humidifies the interior of the greenhouse and produces water from the humid air. The produced water can be used both for irrigation and human consumption. Many factors affect the performance of a seawater greenhouse. In this study, using artificial neural networks, the effects of greenhouse width and length, first evaporator height, and roof transparency on the water production and energy consumption of a seawater greenhouse were examined with the help of Support Vector Regression (SVR) method. A suitable structure was obtained for this method, and %AARE, RMSE and R^2 statistic measures were used for evaluating the performance of the network. This method shows the favorable correspondence with experimental data. Using the prepared optimized network, the effect of each parameter on water production and energy consumption was examined for a wide range of variations in the parameter values. Finally, a 125 m wide, 200 m long greenhouse with a 4 m high evaporator and permeability of 0.6 was found to be the optimum configuration, offering a daily water production of 161.6 m^3 for 1.558 kWh of energy consumed per cubic meter of water produced.

1. Introduction

Given the population growth and the increasing demand for freshwater resources, many countries, even in coastal regions, are facing difficulty supplying water. In many regions, the available water is either too saline or polluted, making it unfit for irrigation or consumption. Therefore, the need for desalination is felt more than ever. Different desalination methods have been proposed, with distillation and reverse osmosis being the most popular, but criticized for their energy consumption and environmental impact.

Many efforts have been made in recent decades to reduce water consumption in agriculture in order to save water and prevent waste. A suitable, low cost method for agricultural applications is the seawater greenhouse which is equipped with humidification and dehumidification (HD) desalination. This method offers advantages such as flexibility in capacity, lower installation and operational costs, simplicity and sustainable energy resources [1–6]. The HD process mimics the natural hydrological cycle. In the HD process seawater or brackish water is heated in a solar water heater. The heated saline water evaporates in a humidifier where it is brought in contact with air. Air saturated with humidity is driven to a dehumidifier where its humidity content condenses to produce fresh water [7]. Humidification–dehumidification (HD) desalination which has a simple technology is a suitable choice for producing fresh water when demand is decentralized [5]. Recent efforts to improve this technology are ongoing [7–15]. Therefore, this technology has been combined with the greenhouse.

Seawater greenhouse is a desalination plant that uses solar energy and seawater. In this method, water is produced by air-dehumidification of the greenhouse. The produced water can be used both for irrigation and human consumption. Given that the system uses solar energy, it saves energy very efficiently while offering low building and maintenance costs due to fewer mechanical parts implemented in it. Greenhouses are built when the outside environment is not suitable for plant growth. Irrigation is improved significantly in this method compared to traditional methods. The key practical point about this type of greenhouse is that the facility can refine water itself so as to be used for agricultural purposes. The success of this design depends on environmental conditions. The greenhouse is suitable for hot, sunny and dry coastal regions with steady winds [16]. The seawater greenhouse is self-sufficient for irrigation of the products cultivated in or around the greenhouse, thus being a great choice for hot and dry regions with low perspiration.

Even though desalination by reverse osmosis and distillation are

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being extensively studied, there have been limited researches on the seawater greenhouse which uses from humidification-dehumidification process

Goosen et al. [17] experimentally studied different parameters of the seawater greenhouse for producing water. Moreover, examining a thermodynamic model based on mass and heat balance, they found greenhouse dimensions to be very effective for production of freshwater capacity and energy consumption while the height of the evaporator has no significant effect. The daily water production of the studied system was 125 m^3 with 1.16 kWh of energy consumed per cubic meter of producing water. Three different climates were assumed within the greenhouse: normal temperature, tropical and desert. The results suggest the highest production of freshwater to occur under desert conditions and the least energy consumption under tropical conditions. They also examined the effects of greenhouse length and width, evaporator height and roof transparency on freshwater production and energy consumption. Assuming different greenhouse areas, they considered three evaporator heights and different roof transparencies in their simulations and found the best configuration for the production of freshwater to be a 200 m width, 50 m length, 2 m first evaporator height and roof transparency of 0.4, that produced 125 $m^3$of water a day.

Davies and Paton [18] studied a seawater greenhouse located in the UAE. The effects of semi-opaque boards, perforated boards, and rows of tubes as three structural elements for making shadows were experimentally compared in their production of freshwater and cooling performance. Their results suggest incorporating semi-opaque boards slightly improve production of freshwater and cooling, while perforated boards significantly increase production of freshwater and rows of tubes enhance production of freshwater and slightly decrease the temperature inside the greenhouse.

Perret et al. [19] examined a type of such systems for implementation in hot and dry regions. Two condensers were incorporated in this system in order to increase the efficiency of condensation. The experimental results showed the humidity to be increasing to the saturation level after the second evaporator, and the temperature of water in the condenser to be always less than the dew point of air current, thus permitting condensation. The results showed the humidity at the outlet of the second evaporator to be 100% most of the time. The low condensation in the condenser was reported to be due to the high velocity of the inlet air, which does not provide enough contact time for the air. The two evaporators incorporated in this project were 5 m long, 1.5 m high and 10 cm thick and were embedded in a wooden case with small wheels so as to investigate their effects as they were moved to different parts of the greenhouse. Cross-flow finned condensers were implemented in this system to provide under-dew-point conditions for the air. Similar to evaporators, the condensers were also designed with embedded wheels so they could be moved to different parts of the greenhouse.

Dawoud et al. [20] examined different solutions for cooling the seawater condenser. Possible cooling techniques for condensers include the use of evaporative cooling for surface seawater, use of closed loop refrigerant coolers, and use of deep groundwater as the refrigerant for the condenser.

In order to study the feasibility of utilizing a combination of energies in seawater greenhouse desalination facilities, Mahmoudi et al. [21] studied the wind-solar hybrid system. They used this hybrid system to obtain the energy needed for supplying water without using fossil fuels. Their reports show that a greenhouse of 60 m length and 16 m width offers a production of freshwater capacity of 297 L/day.

Many models have been proposed for examining and optimizing the behavior of seawater greenhouses. Tahri et al. [22] presented a mathematical model based on energy and mass equations. In order to evaluate the theoretical model, the condenser of a seawater greenhouse located in Muscat, Oman was investigated. The dimensions of the condenser were $0.8 \times 1.9 \times 15$ m, including 320 rows of tubes with an inclination of 30° with respect to the air inlet. Each row had 14 similar 32 mm vertical tubes of 200 μ thickness and 1.8 m height. The proposed model had 5 stages. Information was gathered step by step and finally the mass flow rate of the produced water was calculated in the fifth stage.

In order to simulate the distillation of water vapor in the seawater greenhouse condenser, Tahri et al. [23] presented two models. In fact, their goal was to develop a mathematical model based on mass transfer. They compared the volume of distillates suggested by the two models with experimental results. Using the developed model, they found the rate of distillation expected by the model to be very close to the distillation measured by the thermal model. Moreover, they explained the effects of relative humidity, seawater temperature, air velocity and radiation rate on the water distillation. Sablani et al. [24] were performed a thermodynamic simulation on the influence of seawater greenhouse parameters on a desalination process using humidification-dehumidification with the growth of crops in a greenhouse. Mahmoudi et al. [25] were developed a mathematical model for a new proposed passive condenser in order to increase the performance of a humidification–dehumidification Seawater Greenhouse desalination system.

Based on the composite desirability function, Yetilmezsoy et al. [26] introduced an experimental model for predicting mass condensate flux in the condenser of a seawater greenhouse located in Al-Hail, Muscat, Oman.

So far, there have been no studies incorporating smart methods for predicting the behavior of such greenhouses. These methods provide a better perception of how such a system works. Statistical learning methods, such as Multiple Linear Regression (MLR) or Artificial Neural Networks (ANN), are being extensively used in many researches in different fields of engineering [27]. Recent advancements in statistical learning methods have led to a novel theory called Support Vector Machines (SVMs), a nonlinear solution for classification and regression [28,29]. The SVM method is based on the statistical learning theory and finds a prediction rule for output values that also works for new inputs. ANN and SVM can be used in similar applications; however, a great advantage of SVM over ANN is that the solution provided by SVM is a global minimum, while ANN might yield a local minimum as the solution. Moreover, SVM does not depend on the dimensionality of the input space and offers simple geometrical interpretations and sparse solutions [30].

The goal was to simulate the parameters influencing the seawater greenhouse using the Support Vector Regression based on the available data. The general aim of this study is to examine the effect of changes in length and width of the greenhouse, evaporator height and transparency coefficient on production of freshwater and energy consumption. Essentially, we are looking for optimum conditions that lead to maximum production of freshwater and minimum energy consumption for a given greenhouse.

2. Seawater greenhouse working mechanism

A simple seawater greenhouse consists of two evaporative coolers (evaporators), a condenser, fans, seawater and distilled water pipes and crops in between the two evaporators. Fans blow the air from outside in the first stage, the air then passes the first evaporator with seawater (that are colder than the outside air) on its other side. The outside air, exchanging heat with the seawater, cools down and gets humidified as it passes the first evaporator, the humid, cool air then enters the greenhouse. In the greenhouse, sun rays heat up the air, thus providing the suitable conditions for plants to grow. The air, having relatively low humidity, is not favorable for extracting water from; therefore, it is conducted toward the second evaporator which, similar to the first, has seawater pipes on its other side. It should be noted that the seawater is preheated in the first evaporator and then heated sufficiently in the solar thermal collectors on the roof of the greenhouse before flowing through the second evaporator. In the next stage, passing through a