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Influence of Operational Parameters in Mass Condensate Flux of Condenser of the Seawater Greenhouse

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Abstract: The main objective of this theoretical work was to study the influence of the operational parameters such as the seawater temperature, the humid air flow and the seawater flow on fresh water produced by desalination in the condenser of an existing seawater greenhouse that is located in Muscat, Oman. The theoretical results show that, the mass condensate rate of the system increases with the development of the humid air flow. Then, the seawater temperature and the seawater flow affected negatively the mass condensate rate.

Key words: Condenser; influence; seawater temperature; humid air flux; seawater flux.

1. Introduction

Agriculture accounts for around 70% of all fresh water consumed worldwide. In the Middle East and North Africa region, this goes above 85% and in Oman it is 94%. Unprotected outdoor cultivation can demand more than 4 times the amount of irrigation water, as compared with shaded or more protected cultivation [1]. Inevitably, irrigation demand puts considerable pressure on renewable water resources which often leads to groundwater deficit. The economical and social consequences are apparent in many coastal regions of arid countries such Oman where the overuse of groundwater has caused saline intrusion, which in turn has reduced the ability to grow crops and resulted in agricultural land being discarded [2]. Arid countries may suffer from lack fresh water but they generally benefit from great solar energy potential. Thus, solar desalination may provide a sustainable solution to supply dry regions with fresh water [3]. Indeed, solar distillation projects have been demonstrated in several locations around the world [4, 5].

The seawater greenhouse is a new development that produces fresh water from sea water, and cools and humidifies the growing environment, creating optimum conditions for the cultivation of temperate crops [6]. The use of greenhouses in arid regions decreases crop water requirements by reducing evapotranspiration. The plastic cover utilized on these structures changes locally the radiation balance by entrapping long-wave radiation and creates barrier to moisture losses. As a result, evapotranspiration is reduced by 60 to 85% compared to outside the greenhouse [7]. The concept of the seawater greenhouse has been developed in collaboration with a number of distinguished research organizations and tested with a prototype on the Canary Island of Tenerife [8]. The Solution lies in augmentation of fresh water resources [2]. The high cost of fuel-powered desalination (multi-stage flash and reverse osmosis) does not render these techniques feasible for arid land agriculture [9]. An example of seawater greenhouse system is a pilot plant at Al-Hail, Muscat, in the Sultanate of Oman. Thermodynamic modeling has shown that the dimensions of the greenhouse have the greatest overall effect on the water production and on the energy consumption. Low power consumption went hand-in-hand with high efficiency. A wide shallow greenhouse, 200 m wide by 50 m deep gave 125 m^3 per day of fresh water. This was greater than a factor of two compared to the worst-case scenario with the same overall area (50 m wide by 200 m deep), which gave 58 m^3 per day. Low power consumption went hand-in-hand with high efficiency. The wide shallow greenhouse consumed 1.16 $KWhm^{-3}$, while the narrow deep structure consumed 5.02 $KWhm^{-3}$ [10]. The system consists 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 [11]. In a similar study, a closed-air cycle humidification-dehumidification process was used by Al-Hallaj et al. [12] for water desalination. The humidification-dehumidification method was used in a greenhouse-type structure for desalination and for crop growth [6]. Their seawater green- house 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 [13]. The greenhouse is equipped with humidification–dehumidification devices which create the proper climate to grow valuable crops and at the same time produce freshwater from saline water. The hybrid systems consist of a combination of wind machines with photovoltaic solar cells. The need to employ the greenhouse in coastal and isolated regions has driven the search for energy from renewable sources such as wind and solar power [14].

An overview on the possible cooling technologies of the condenser of a seawater greenhouse desalination technique has been given. The possibilities to cool the cooling water of such condenser are to apply evaporative cooling for surface seawater, to make use of a cooling machine, or to utilize deep seawater as a condenser coolant [15]. After the work of Merkel [16], who developed the basic theory of evaporative cooling, Berliner [17] has described the basics of calculating and constructing different types of cooling towers. Poppe and Rögener [18] developed design algorithms for evaporative cooling systems.

The main objective of this work was presented an investigation determining the number of degree freedom of the condenser the principal unit of our study. The theoretical work study by simulation of the condenser using the model developed according to Tahri et al. [19], the influence of the operating parameters such as the seawater temperature, the humid air flow and the seawater flow on fresh water produced by desalination in the condenser of seawater greenhouse.

2. Condenser process description

The condenser of the seawater greenhouse is a heat exchanger where the seawater is the coolant and the humid air is the hot fluid. The condenser (Fig. 1) consists of a set of 302 rows of parallel tubes arranged vertically and with an angle of 30 degrees with the direction of flow of humid air. Each row has 14 identical vertical tubes with diameter of 33 mm (D) and a height of 1.8 m (L). The arrangement of the tubes was organized to ensure the passage of coolant from one tube to another. All tubes passes in a single row have the form of a coil. Seawater enters with a constant speed (u_{sw}) and a known temperature (T_{swin}) in the first row of each tube and it leaves the last tube in the same row with a temperature T_{swout}. The humid air from the second evaporator runs perpendicular to the condenser. It enters through the tubes with a velocity (v_{air}), temperature (T_{dbin}), and a relative humidity (RH_{in}). This humid air will leave the condenser with the same speed v_{air}, with a temperature of T_{dbout} and a relative humidity of RH_{out}. The contact of humid air with the outer cold surfaces of the tubes of the condenser (in which seawater is flowing) will result in the condensation of the water vapor in the humid air at the outer surfaces of these tubes. The produced condensate which will be formed as a liquid film of low thickness will descend along the tubes to be collected in the reservoir of fresh water [19].

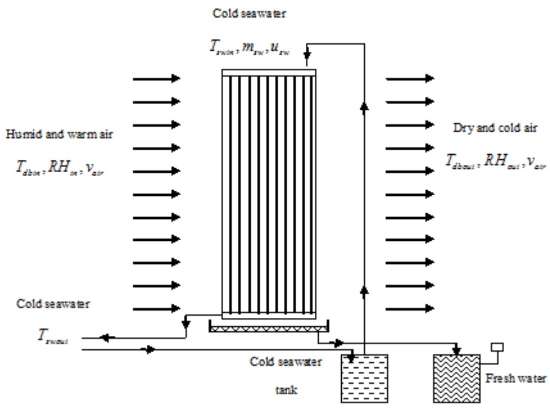

Figure 1 : Process schema of the condenser used in the seawater greenhouse

3. Simulation of operational parameters of condenser

The simulation of the condenser leads necessarily to determine:

- The temperature profile of the two fluids;
- The heat exchange coefficient;
- The mass condensate rate.

Depending on various design variables of the condenser and given the complexity of interactions between variables on the one hand and to ease the model on the other hand, we felt more appropriate to use the method for determining the number of degree freedom of the condenser.

To determine all the design variables which can be controlled externally, we have preceded by analysis of degrees of freedom of every element present in the condenser based primarily on the Gibbs phase rule on one hand and conservation laws of matter and energy on the other hand. The number of degrees of freedom (N_D) was calculated by the following equation:

$$N_D = N_V - N_E \quad (1)$$

It is clear that this process greatly facilitates the choice of design variables and improves the conditions of treatment when called digital computer use in the simulation step.

3.1. Application of the concept of degrees of freedom to analysis the condenser

The condenser is the heat exchanger where interacted 4 currents which were monophasic. The number of components of the current is (C), and then we can associate (C+3) variables that can be specified as follows:

1.	Mole fractions (x_i)	C
2.	Flow (m)	1
3.	Pressure (P)	1
4.	Temperature (T)	1

It is important to note that, in a condenser, the only possible interaction is the interaction thermal between currents.
It follows that the number of degrees of freedom of the condenser is 11. However it is necessary to add the following simplifying assumptions:

- The pressures of inlet and outlet currents are equal to atmospheric pressure
- Salt concentration of cold fluid (xi) is constant and equal to 0.35 g/l

Ultimately, the number of degrees of freedom of the condenser is 6, which can be enumerated as follows:

- Air humidity at the entrance;
- Air temperature at the entrance;
- Flow of dry air;
- Flow of coolant (seawater);
- Seawater temperature at the entrance;
- Total number of tubes in the condenser.

3.2. Pelage change settings

At this stage, we can announce that the model developed in this work reflects very faithfully the dynamic behavior of the condenser of the greenhouse. It is quite obvious that the optimal performance can not be achieved if the analysis of the influence of parameters is studied. So, the next part will be dedicated to the study of actual conditions of operation of the greenhouse. For this purpose, we defined the ranges of variation of different parameters. Thus, we note:

• Relative humidity of inlet air dry (RH_{in}) varies from 0.8 to 0.98.
• The inlet temperature of humid air (T_{dbin}) varies from 30 to 50°C.
• The temperature of the seawater at the entrance (T_{swin}) varies from 20 to 30 °C.
• The mass flow of humid air input (m_{air}) varies from 11.74 to 23.48 kg/s.
• The mass flow of entry of sea water (m_{sw}) varies from 3.81 to 14.52 kg/s.

The values of inlet relative humidity and inlet dry bulb temperature of humid air was used in the calculation of the adiabatic saturation temperature (T_{sat}) for the first and the last tube in the row of the condenser [19] according to Eq. (2):

$$\frac{H_{sat} - H}{T_{sat} - T_{db}} = -\frac{C_s}{h_{fg}} \quad (2)$$

Firstly, the inlets dry bulb temperature (T_{dbin}) was used in the calculation of the pressure of the water vapor at the adiabatic dry bulb temperature $(P_{sat})_{T_{db}}$ for each tube of the condenser [19] according to Eq. (3):

$$Log_{10}(P_{sat})_{T_{db}} = 8 - \frac{1689.52}{230 + T_{db}} \quad (3)$$

The relative humidity (RH_{in}) was used in the calculation of the partial pressure of water vapor (P_{vap}) in the air-water mixture for each tube [19] according to Eq. (4):

$$P_{vap} = (P_{sat})_{T_{db}} \ RH \tag{4}$$

The values of the temperature of the seawater at the entrance (T_{swin}) was used in the calculation of the heat flux (Q) for each tube [19] according to Eq. (5):

$$Q = U \ A_s \frac{(T_{sat} - T_{swin}) - (T_{sat} - T_{swout})}{\ln\left(\dfrac{(T_{sat} - T_{swin})}{(T_{sat} - T_{swout})}\right)} \tag{5}$$

The values of the mass flow of entry of sea water (m_{sw}) was used in the calculation of the heat flux transferred from the humid air to the seawater (Q_{sw}) in the first tube according to Eq. (6):

$$Q_{sw} = \rho_{sw} \ u_{sw} \ C_{P\,sw} \ \pi \ \frac{(D_{in})^2}{4} (T_{swout} - T_{swin}) \tag{6}$$

The values of the mass flow of entry of sea water (m_{sw}) was used in the calculation of the heat flux of air (Q_{air}) in the entrance of the first tube according to Eq. (7):

$$(Q_{air})_{in} = (h_{air})_{in} \ m_{air} \tag{7}$$

4. Results and discussions

4.1. Influence of inlet seawater temperature

The influence of the inlet seawater temperature in fresh water produced by desalination in seawater greenhouse at Al-Hail, Muscat, Oman, is shown in Fig. 2. For condensation conditions dictated by the vapor pressure of the gas phase, any increase of (T_{swin}) results in the displacement of temperature differences to the unfavorable areas. This shows that decreasing linear tendency is observed when the inlet temperature of the cold current (T_{swin}) increases, the outlet temperature of seawater consequently increases in a linear fashion with a negative impact on the mass flow of condensate. An average temperature of 25°C seems to flow trampling the optimal performance of the process. We note that the regression rate of condensate flow is $\dfrac{\Delta m_c}{\Delta T_{swin}} = -0.35$.

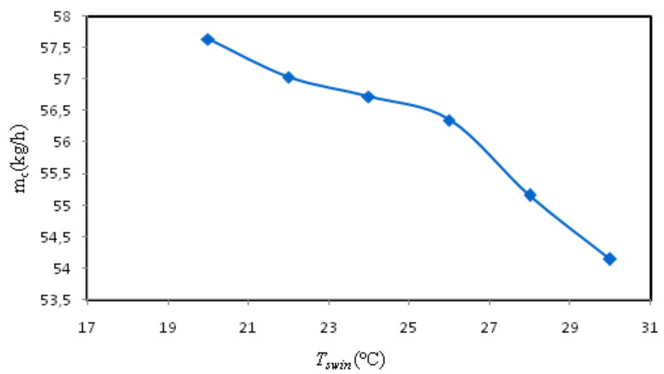

Figure 2. Influence of seawater temperature on fresh water produced by desalination in seawater greenhouse at Al-Hail, Muscat, Oman.

4.2. Influence of inlet humid air mass flow

Figure 3 shows the influence of the inlet humid air mass flow in fresh water produced by the condenser in the seawater greenhouse at Al-Hail, Muscat, Oman. Any increase in mass flow leads to an increase in the amount of heat the incoming air and therefore the temperature of incoming air, thus increasing the flow of condensate. Indeed, any increase of speed of the humid air flow is spotted by an intensification of heat exchange given the impact of turbulence on the one hand reduces the film thickness of condensate and promoting the transfer of vapor to the tube wall on the other. We note that the rate of increase of condensate flow is $\dfrac{\Delta m_c}{\Delta m_{air}} = 0.6$.

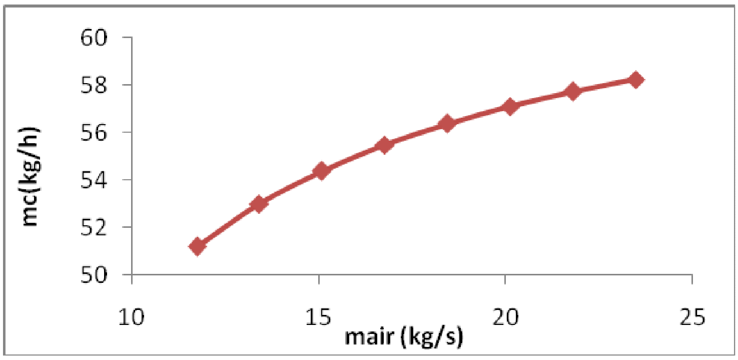

Fig. 3. Influence of air flow on fresh water produced by desalination in seawater greenhouse at Al-Hail, Muscat, Oman.

4.3. Influence of inlet seawater mass flow

The influence of the inlet seawater mass flow in fresh water produced by desalination in seawater greenhouse at Al-Hail, Muscat, Oman, is shown in Fig. 4. It can be noted that the simulation results give an decreasing trend of the curve $m_c = f(m_{sw})$. It is clear from the figure that as the inlet seawater mass flow decreases, the mass condensate rate is decreased. This situation offers better conditions for condensation and consequently the performance of the greenhouse. It can be noted that the regression rate of condensate flow is $\dfrac{\Delta m_c}{\Delta m_{sw}} = -0.935$.

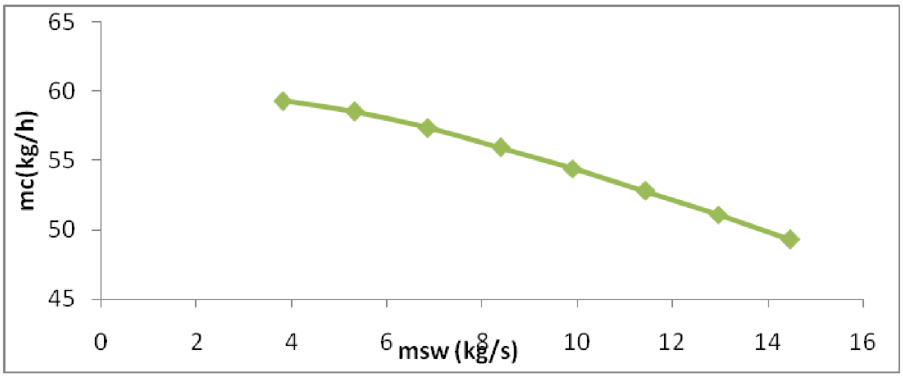

Figure 4 : Influence of seawater flow on fresh water produced by desalination in seawater greenhouse at Al-Hail, Muscat, Oman.

5. Conclusion

This paper presented an investigation determining the number of degree freedom of the condenser the principal unit of our study. We discussed in this work the simulation of the influence of the operating parameters such as the seawater temperature, the humid air flow and the seawater flow on fresh water produced by desalination in the condenser of seawater greenhouse. The results showed the influence of these parameters on the flow of condensate. It can be noted that the condensate flow rate increases with air flow. But the temperature of seawater and the flow of seawater affect negatively the flow of condensate.

Nomenclature

A_s	heat transfer area	v	velocity
C	number	y_i	number of composition
C_p	specific heat	x_i	number of composition
C_s	humid heat	*Subscripts*	
D	diameter	air	air
H	absolute humidity	c	condensat
h	enthalpy	D	degrees of freedom
h_{fg}	latent heat of vaporization	db	dry bulb
m	mass flux	E	equation
N	number	in	inner
P	pressure	sat	saturation

Q	heat flux	sw	seawater
RH	relative humidity	swin	seawater inlet
T	temperature	swout	seawater outlet
U	overall heat transfer coefficient	V	variables
u	speed	vap	vapor
Greek symbols			
ρ	density		

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