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Study of thermophysical properties of a solar desalination system using solar energy

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ABSTRACT

Salted water occupies the greatest part in the world, but we are not using all of it because of its saline character. In addition, there is an excessive consumption of energy in most systems of desalination which leads to generating gases that cause global warming. Besides, in certain countries of the world this energy is not available in great quantity. Distillation is an operation which transforms, by heating, the seawater or brackish water into vapor. Through condensation, this vapor gives water of great purity. Among the various processes, solar distillation is an interesting solution in the isolated areas. The objective of our work is to study the transfers of heat and mass in a solar distillatory. Thus, we studied the evaluation of the thermophysical properties and the effect of the properties of humid air—as binary mixture of water vapor and dry air—on the coefficient of transfer of heat by convection and the evaporative ratio of thermal coefficient of transfer and the flow of the distillate. In addition to these theoretical results, we have replicated previous experimental investigations. We have also established equations governing the operation of a solar distiller with capillary film, in the resolution based on the numerical approach based on the method of Runge–Kutta. The results obtained show that the effect of relative humidity and the differences in temperature between the pan and brine on the convective coefficient and thermophysical parameters of solar distiller.

Keywords: Humid air; Thermophysical properties; Solar distiller; Efficiency

1. Introduction

Three quarters of the surface of our planet are covered by water, but unfortunately salt water which is unfit for human consumption contains about 35 g of salt per liter [1].

There are different possibilities of transforming the salt water to fresh water for consumption. The two methods most commonly used are distillation and reverse osmosis, whose principles are very simple [2]. Various technical processes have been developed in recent decades to demineralize seawater and/or brackish water. Among the best known, and without being exhaustive are: the thermal processes with phase change (or distillation) as [3]. These heat the seawater to vaporize a portion. The steam does not contain salt,

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it is sufficient to remove the steam to the liquid state by cooling it for drinking water. The major disadvantage of distillation processes is their high-energy consumption due to the latent heat of vaporization of water. Processes that allow multiple effects to reuse the energy released during condensation have been developed [4]. In modern distillers, the working temperature is between 5 and 125˚C. The salinity of fresh water obtained is below 100 mg/l [5]. A technique that uses solar radiation to heat the salt or brackish water in a tray covered by a sloping glass. Part of the water evaporates and the steam produced is liquefied on the inner surface of the glass [1] for this parameters affecting the operation of the distiller that depends on quantities known as "operating characteristics" (the flow of distillate the overall efficiency and internal) that are usually influenced by operating parameters. It may have classified them into two categories, the external parameters and internal parameters [6]. For this, we will determine the theoretical and numerical values.

2. Theoretical and numerical study of a capillary film solar distiller

2.1. Description and operating principle

The device is a cell formed by two rectangular metal plates (1 m × 1 m) arranged vertically opposite each other as shown in Fig. 1. The brackish water to be distilled slowly flows by gravity to one side of the metal plate. Its testability is provided by a fabric (gauze) that adheres by capillary action on the entire surface runoff. The other side of the same plate is painted black and is exposed to solar radiation constituting the plate evaporator.

The water vapor produced leaves the fabric (gauze) and will condense on contact with another plate which is right in front of the condensing plate. The water is distilled and collected at the foot of the same plate by condensing a collector. The residue is collected, also at the foot of the plate by evaporating another collector.

2.2. Bilan thermal

Before establishing the overall energy balance of the distiller study is to determine, first, the main heat transfer inside and outside the system. Namely, solar radiation striking the surface of the glass is absorbed by the glass and the absorbing surface (absorber–evaporator).

- The glass gives the surrounding environment; the heat flux is $Q^{r}V-a$ by radiation and $Q^{c}V-a$ by convection.
- For convection, the window receives the evaporator; a heat flux $Q^{c}ev-V$.
- The exchange with the evaporator and condenser heat fluxes $Q^{r}ev-cd$ by radiation and $Q^{c}ev-cd$ by convection.
- The condenser transfers to the environment, the heat flux $Q^{r}cd-a$ by radiant and $Q^{c}cd-a$ by convection.

2.3. Assumptions simplifying

Simplifying assumptions have been adjusted as follows:

- The sky is seen as a black body.
- The side walls are assumed insulated well.
- Dissolved salts have no influence on the quantities of heat exchanged by the brine.
- The heat losses from the extraction of the distillate are neglected.
- The thermal inertia of the coverage is low.
- The temperature of each plate and the cover glass is assumed uniform.
- The wall of condensation is not wettable.
- The water to be evaporated, the concentrate and distillate are very capillary films and their temperatures are equal to the temperature of the metal wall in contact with the films.
- The plates are equidistant.
- The physical properties of the glass plates and are considered independent of temperature and is taken equal to the mean values.

2.4. Computer processing

(a) The first step is to calculate the thermophysical properties of moist air, the coefficient of heat transfer by convection, the ratio of evaporative heat transfer by convection and flow of distillate.
(b) The calculated different thermal exchanges which are independent of temperature, namely the coefficients of heat transfer by conduction and heat transfer coefficients due to wind.
(c) It is calculated at each time of day:

  - Solar radiation.
  - The power absorbed by the glass and the evaporator.

(d) It is assumed that the various components of the distiller are at room temperature, except that the evaporator is at a higher temperature, and is calculated for the initial temperatures:

The properties of the brine:

- Density.
- Thermal conductivity.
- The dynamic and kinematic viscosity.
- Heat capacity.
- Latent heat of vaporization.
- The coefficients of heat exchange by radiation between the glass and the sky, between the glass and the evaporator and condenser and between the ambient environment.
- The coefficients of heat transfer by convection between the glass and outside.
- The evaporator and the glass.
- The evaporator and condenser.
- The coefficient of heat exchange by evaporation from the brine and the condenser.
- Resolution of the system of equations by the method of Runge–Kutta of order 4.

(e) Reprise with the temperatures obtained.
(f) Calculation of the overall and internal performance.

The evaluation and the effect of thermophysical properties of moist air (binary mixture of water vapor and dry air) on the coefficient of heat transfer by convection in a solar still are the subject of this last part of memory.

The calculations were carried out, pursuing geographical coordinates at one-hour time difference.

- Calculations are performed from an initial time t_0 for each component of the distiller, at an initial temperature and with a time step equal to one hour.
- The slope of the distiller is 30˚C to the horizontal with an azimuth of 0˚C to the south.

3. Results of thermophysical properties

3.1. The density

The density of the mixture of dry air and water vapor is plotted as a function of temperature ($0 < T < 100$˚C) relative humidity ranging from RH = 0%, corresponding to the dry air (upper curve), to RH = 100%, relative to that of saturated air (lower curve), is shown in Fig. 2. An analysis of the curves of this figure can be noted that the intermediate curves have the same shape that are unclear and at low temperatures from 50˚C—a lag of about 10% appears between them. On the one hand, for a given relative humidity, the density decreases with increasing temperature; and on the other hand, for a given temperature from 50˚C, the density decreases gradually as the mole fraction of water vapor increases as shown in Fig. 2.

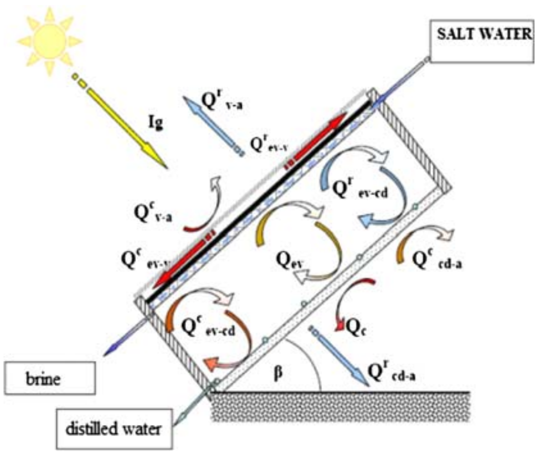

Fig. 1. Capillary film solar distiller.

3.2. The viscosity

The effect of temperature on the viscosity of the mixture at a relative humidity ranging from RH = 0% (upper curve) to RH = 100% (lower curve) is shown in Fig. 3 which shows that at a temperature of 40˚C the viscosity increases slightly with temperature but the humidity has no significant effect (the curves are almost together) by cons from 50˚C the viscosity decreases and this decrease is to especially emphasizes the states close to saturation.

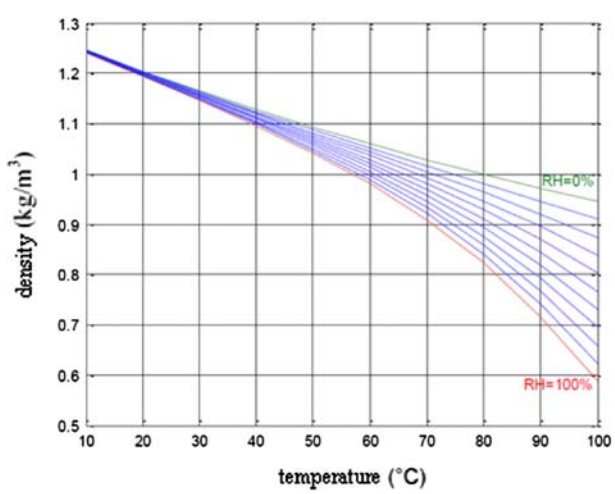

Fig. 2. Density of moist air at relative humidity.

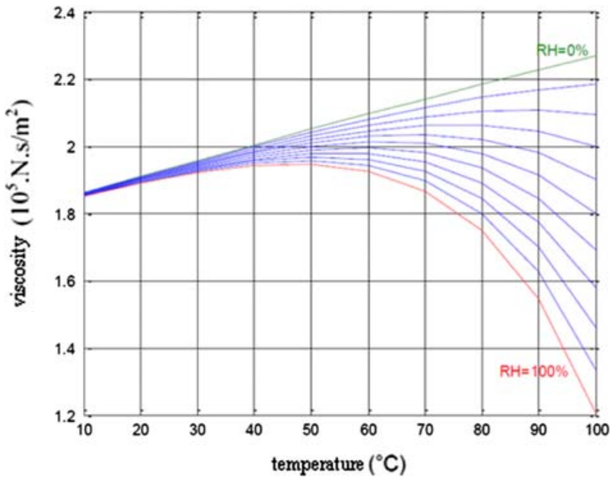

Fig. 3. Viscosity of moist air relative humidity between 0 and 100%.

3.3. The heat

The effect of temperature on the specific heat of the mixture (values derived from the equation) at different relative humidity is studied (Fig. 4). We can see that at low temperatures of 50–60˚C, the relative humidity has little influence on the specific heat of the mixture and in excess of these values, particularly from 80˚C, the effect is important as we approach the state of saturation.

3.4. The thermal conductivity

It is easy to observe in Fig. 5 that low temperatures (up to 40˚C) and humidity have little influence on the thermal conductivity of moist air at temperature above 80˚C or the effect becomes more pronounced especially for states close to saturation.

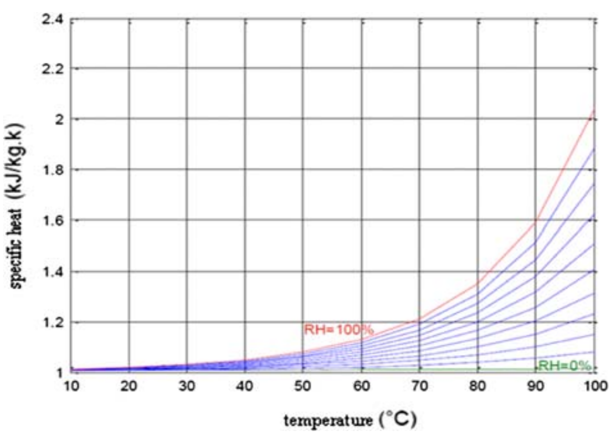

Fig. 4. Specific heat of moist air relative humidity between 0 and 100%.

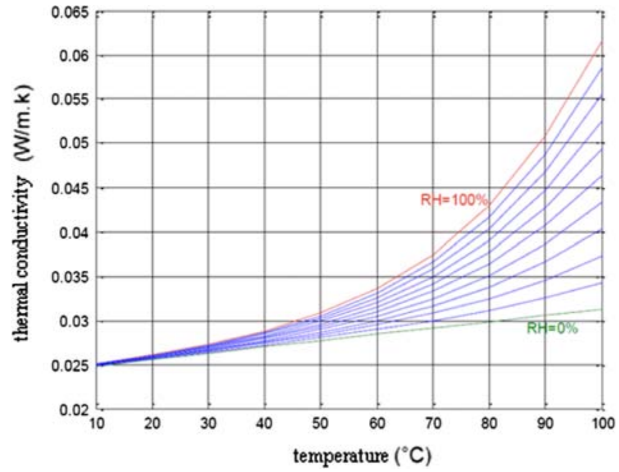

Fig. 5. The thermal conductivity of moist air relative humidity between 0 and 100%.

3.5. The thermal diffusivity

The shape of the curves in Fig. 6 representing the variation of thermal diffusivity as a function of temperature for different values of relative humidity of moist air that is similar to that found for the thermal conductivity.

3.6. Exchange coefficient by convection

It is easy to note that at a relative humidity of 100%, the curves (Fig. 7) representing the variation of

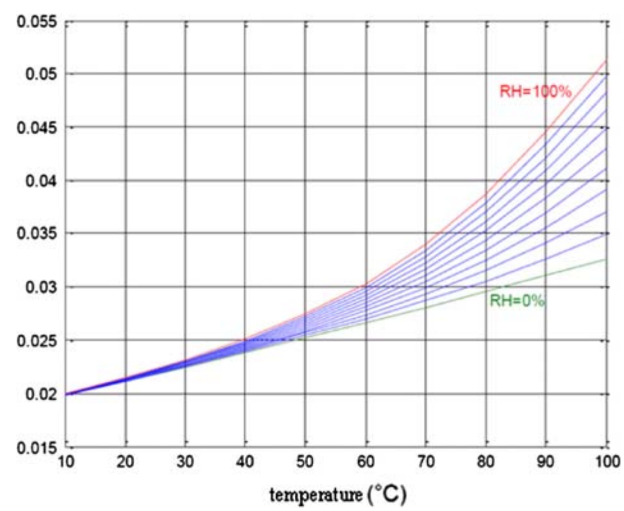

Fig. 6. Thermal diffusivity of moist air relative humidity between 0 and 100%.

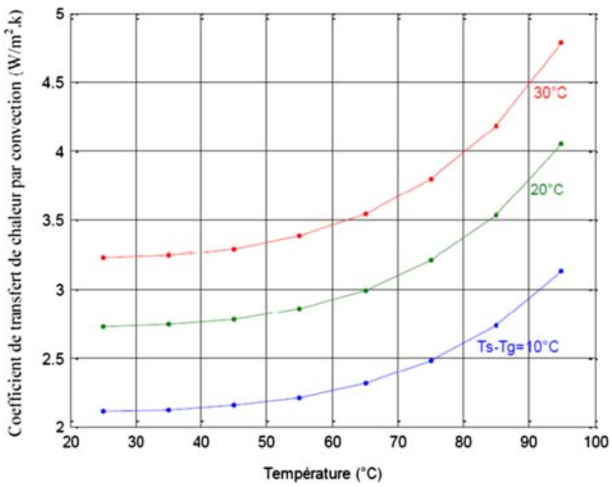

Fig. 7. Variation of convective heat transfer coefficient function of temperature and different variances (T_s–T_g).

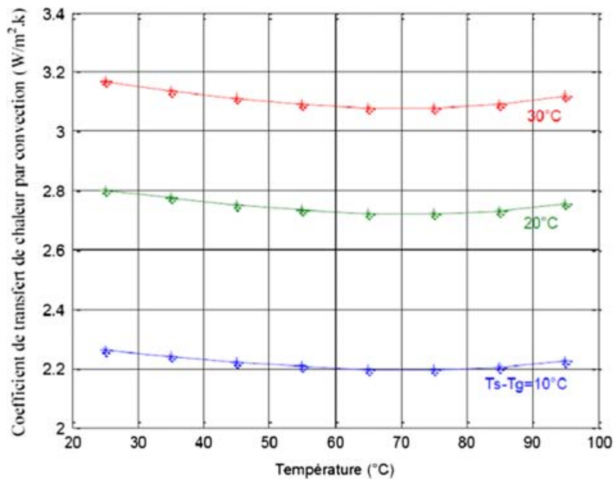

Fig. 9. Variation of the coefficient of convective transfer in function of temperature and different variances (T_s–T_g).

the coefficient of heat transfer by convection according to the average temperature differences at different variances (T_s–T_g) is not linear. We can see that the different curves are slightly growing at low temperatures and above 50˚C, growth becomes more rapid.

In addition, Fig. 7 shows clearly that the convective coefficient increases with the temperature difference between brine (Plan evaporation) and glass (surface condensation). Coefficient of heat transfer by convection (W/m^2 K).

The same observations will be recorded at a relative humidity of the mixture of 50%. However, it appears that for a given temperature the exchange coefficient by convection is less important in this case (Fig. 8). Coefficient of heat transfer by convection (W/m^2 K).

In the case of dry air (RH = 0%), Fig. 9 can be noted that for a temperature difference between brine and the glass, the convective heat transfer coefficient decreases with increase in the average temperature of the air. This influence is even more pronounced than the difference which is important. Coefficient of heat transfer by convection (W/m^2 K).

We have grouped in the Fig. 10, all the curves of variation of heat transfer coefficient with temperature for different relative humidity HR, 0% (dry air), 50% (mixture of dry air and water vapor), and 100% (saturated mixture) and at various temperature differences between the brine and the glass (T_s–T_g) equal to 10, 20, and 30˚C. We can see that up to an average temperature of 50˚C, the variation of exchange

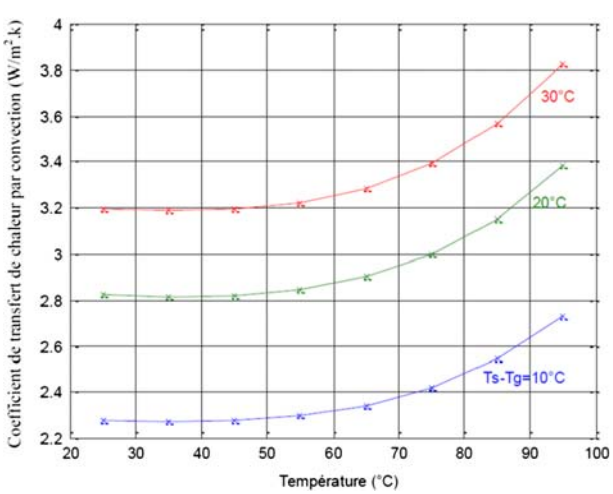

Fig. 8. Variation of the coefficient of convective transfer in function of temperature and different variances (T_s–T_g).

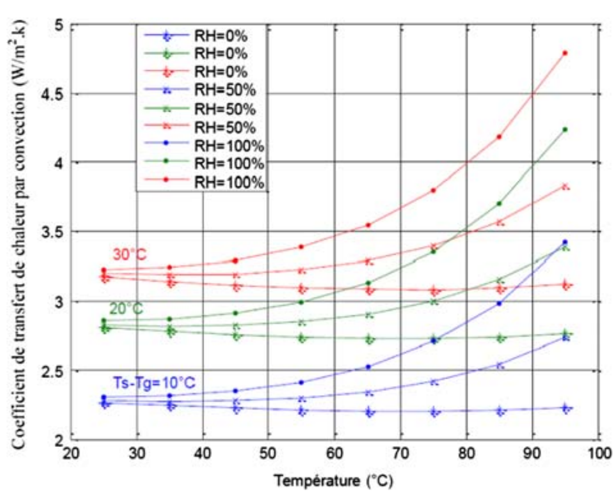

Fig. 10. Variation of the coefficient of convective transfer on the basis temperature differences at different (T_s–T_g) =10, 20, and 30˚C.

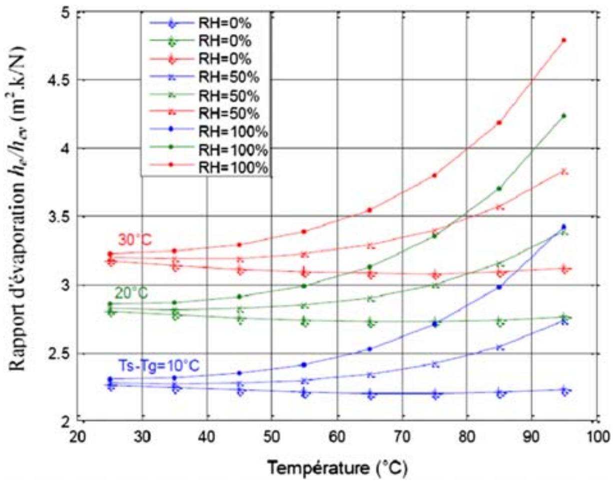

Fig. 11. Variation of the postponement of evaporation with temperature and differences at different (T_s–T_g) =10, 20, and 30˚C.

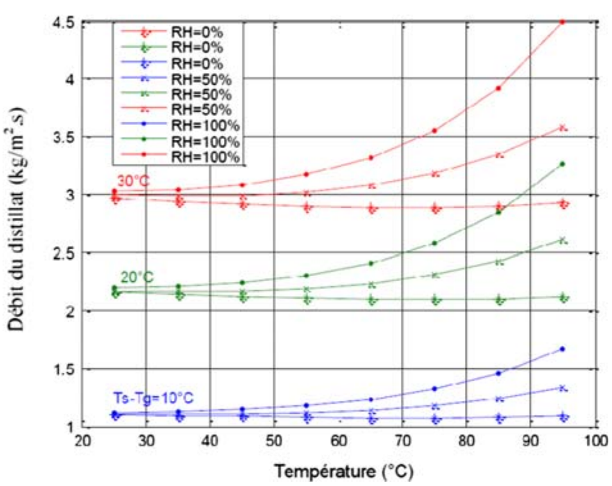

Fig. 12. Variation of flow of distillate with temperature and different variances (T_s–T_g) = 10, 20, and 30˚C.

coefficient is almost linear beyond the effect is more pronounced. Coefficient of heat transfer by convection (W/m^2 K).

The variation of the coefficient of evaporation, the transfer coefficient by convection (*hcv*) with the average temperature of moist air for different temperature differences (T_s–T_g) and at various rates relative humidity HR (Fig. 11) is similar to the coefficient of convective transfer (Fig. 10).

3.7. The mass flow of distillate

The flow of the distillate calculated from the expression, is a function of density, viscosity, thermal diffusivity, and thermal conductivity of the mixture. Fig. 12 helps out regardless of whether the flow increases in all cases with the growth temperature, it is particularly important that the temperature difference between water and the glass is higher.

4. Conclusion

The present work concerns the study of heat transfer and mass within a solar still. After presenting the different types of distillers, we recalled the principle of operation, the main parameters influencing the distillation system and the operating characteristics; and our interest focused on the phenomenon of energy exchange in the operation of a solar still. We set the heat exchange at each part of the distiller and the resulting system of equations was obtained by the method of Runge–Kutta. The results clarified the effect of relative humidity, the difference in temperature between the brine and the glass on the convective coefficient, and thermophysical parameters (density, viscosity, specific heat, thermal conductivity, and thermal diffusivity) of the solar still. It appears that at low temperatures from 50 to 60˚C, relative humidity has little influence on the thermophysical properties of moist air, the convective heat transfer coefficient, and production. In addition, the results obtained show the curves illustrating the temporal variation of the operating characteristics of distillers (production, internal efficiency, and overall) in the shape of a bell that is the same shape as that of the temporal variation of solar irradiance from which it can be deduced that the latter is the parameter most affecting the operation of a solar still.

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