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Thermal analysis of a conical solar still performance: An experimental study

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Abstract

In this paper, an attempt is made to estimate the heat transfer coefficients of a conical solar still. Many researches and development works tried to enhance the productivity of solar stills using different methods. So in this study the productivity enhancement of solar still by decreasing the shadow effect and maximize utilization of solar radiation is discussed. A conical solar still was designed and manufactured at faculty of engineering Sheben El-Kom – Egypt (latitude 30.56 N and longitude 31.01 E). The still base area was 0.8 m^2, and the acrylic cover of still inclined at 31° which equal to the city latitude. The experimental results of conical solar still were compared with a conventional type solar still which has the same area. The results showed that, the daily productivity for conical and conventional solar stills was 3.38 and 1.93 L/m^2 day, respectively. Heat and mass transfer coefficients were evaluated and the Nusselt and Sherwood numbers were calculated with the aid of both evaporation measurements and Chilton–Colburn analogy. The maximum value of the total heat transfer coefficient were 66 and 32 W/m^2 °C for conical and conventional solar stills, respectively. The analogy between heat and mass transfer coefficients was also investigated.

Keywords: Solar energy; Heat and mass transfer; Solar still; Conical

1. Introduction

The need of pure water is important in day-to-day life. The shortage of drinking water is the biggest problem of the world in this century due to population growth and unsustainable consumption rates. The possible water sources are the bore wells, rainwater, and river or lake water. Oceans constitute about 97.5%, and the remaining 2.5% fresh water is present in the atmosphere, surface water, polar ice and ground water. This means that only about 0.014% is directly available to human beings and other organisms (Bendfeld et al., 1998). The limitations of solar energy utilization for desalination are the high initial cost for renewable energy devices and intermittent nature of the solar radiation. Brackish or waste water can be converted into potable water using solar stills (Sampathkumar et al., 2010). El-Sebaii (2000) studied theoretically the effect of wind speed on the performance of some different designs of solar stills. The results showed that, the daily productivity increased as the wind speed increased up to a certain velocity. The analysis of a single-basin solar still with a cooling between a double-glass glazing was performed by Abu-Arabi et al. (2002).

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Nomenclature

A	area of solar still basin, m^2
a and b	constants
C_p	specific heat of vapor, J/kg °C
D	the diffusion coefficient
d	characteristic length of solar still, m
Gr'	modified Grashof number
h_{cw}	convective heat transfer coefficient, W/m^2 K
h_{ew}	evaporative heat transfer coefficient, W/m^2 K
h_{fg}	latent heat of vaporization, J/kg
h_m	The mass transfer coefficient, W/m^2 °C
h_{rw}	radiative heat transfer coefficient from water to cover, W/m^2 °C
h_1	total heat transfer coefficient from water to cover, W/m^2 °C
k	thermal conductivity of the humid air, W/m K
Le	Lewis number
M	molecular weight (kg/mol)
m	number of experimental variables
Nu	Nusselt number
m_{ew}	hourly distillate yields, kg/m^2
P	the total pressure, atm
P_g	partial pressure at cover temperature, N/m^2
Pr	Prandtl number
P_w	partial saturated vapor pressure at water temperature
Q_{cw}	convective heat transfer, W
q_{cw}	convective heat transfer rate, W/m^2
q_{ew}	evaporative heat transfer rate, W/m^2
q_{rw}	radiative heat transfer from water to cover, W/m^2
R^2	the coefficient of determination
Ra	Rayleigh number
R_u	Universal gas constant, J/mol K
T_a	ambient air temperature, °C
T_b	basin temperature, °C
T_w	water temperature, °C
T_g	acrylic covers temperature, °C
T_s	humid air temperatures inside the solar, °C
$\Delta T'$	temperature difference between water and inner acrylic cover, °C
t	time interval, s

Greek symbols

ϵ_{eff}	effective emissivity
ϵ_g	emissivity of acrylic cover
ϵ_w	emissivity of water
σ	Stefan–Boltzmann constant
β	expansion factor of vapor
μ	dynamic viscosity, kg/m s
ρ	density, kg/m^3

They observed that, flow of cooling water between the double-glass cover increased the solar still productivity. The effect of using different size sponge cubes inside the still basin was studied by Abu-Hijleh and Rababa'h (2003). They reported that the sponge cubes can improve the productivity by 18–273%. Solar desalination unit was studied experimentally and theoretically by Abdel-Rehim and Lasheen (2007). They a tested a parabolic concentrator solar energy with focal pipe and heat exchanger. This modification improved the productivity by an average value of 18%.

The effect of internal and external reflectors on solar stills performance was studied by Tanaka (2009). The results showed that, the daily productivity of a basin type still can be improved by 70–100% when internal and external reflectors are used. Omara et al. (2014) improved the performance of stepped solar still by 125% when internal and external reflectors were used. Also the cost of one liter of the yield for stepped still with reflectors decreased by 0.018$. The effect of cover tilt angle of solar still was studied by Khalifa (2011). The results showed that, the cover tilt angle should be large in winter and small in summer, also the optimum cover tilt angle is close to the latitude angle of the site. Omara et al. (2011) studied the effect of different basin shapes on the performance of solar stills. They used finned and corrugated absorbers solar stills. Their results indicate that, using finned and corrugated absorbers improve the productivity of solar stills. In order to increase the productivity of solar stills, Kabeel et al. (2014) used different types of nanomaterials with and without vacuum. They used different nanomaterials concentration between 0.02% and 0.2% with a step of 0.02%. The results showed that, the productivity with using cuprous oxide nanoparticles increased by 133.64% and 93.87% with and without using vacuum fan, respectively. Comparison of plastic and glass condensing covers for solar stills was presented by Tleimat and Howe (1969). Several solar stills of different designs were fabricated and tested with two types of condensing cover. They concluded that the glass cover produced higher productivity than the plastic cover. They found also that the conical solar still had higher productivity than that of the single slope still.

In the present study a conical solar still is designed and fabricated to obtain maximum yield during the day. This device can be fabricated easily with locally available materials. The maintenance is also cheap and no skilled labor is required. Moreover, it can be a suitable solution to overcome drinking water shortage.