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Research paper

Heat transfer coefficients and productivity of a single slope single basin solar still in Indian climatic condition: Experimental and theoretical comparison

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A B S T R A C T

A theoretical and experimental study was conducted at the central Indian location of Rewa, M.P., India (Latitude: 24°33′ 20.81″ N, Longitude: 81°18′ 49.1″ E). This paper presents a detailed comparison of the theoretical and the experimental results obtained for a single sloped basin type solar still. Results for different parameters such as basin water temperature, glass cover temperature, distillate output, evaporative, convective and radiative heat transfer coefficients and attenuation factor were obtained for basin water depths ranging from 2 cm to 10 cm. For solar still, daily distillate output decreased with increase in basin water depth. The theoretical value of daily efficiency for 2 cm and 10 cm basin water depth was around 52.83% and 41.75%, respectively, and for the same basin water depth, experimental daily efficiency was around 41.49% and 32.42% respectively. A sound agreement between the theoretical and the experimental results was observed.

1. Introduction

Nectar is found on earth in the form of water. There is an urgent need of fresh water for the survival of human beings, as without water life is not possible on our planet. More than two third of the earth's surface is covered with water. Ninety-seven percentage of water resources on the earth's surface are found in the form of oceans and seas which contain highly salty water (3000 ppm to 35,000 ppm) and therefore not suitable for human consumption. Only 3% of total water resources on the earth's surface have clean water. More than 2% of fresh water is frozen in the form of glaciers and ice blocks in the polar region and rest of fresh water (less than 1%) is found in the rivers, ponds, lakes and underground water. That small part of fresh water has been the main source of water to fulfill the demand for domestic, agricultural, and industrial activities.

Actually, this fresh water is not fresh according to the international standard as it contains the harmful bacteria and viruses, which are the cause of various water-generated diseases such as cholera, diarrhea, malaria, typhoid and many more, which kill over 3 million people every year. Clean water is a precious commodity and very important for our survival. Due to increase in population and fast industrial development, the requirement of potable water will increase day by day. More and more water purification systems are being developed to cope with fresh water scarcity on the earth. One of the process known as distillation can fulfill this. It is a widely accepted process for converting brackish or impure water into drinkable water by the application of thermal energy (solar or fossil fuels). Solar energy is an ideal solution for powering the distillation process, which is environment friendly, free of cost, never lasting and abundantly available all over the planet.

Solar distillation is one of the best methods for purifying brackish water. Solar still is a device which is widely used in the solar distillation process, but the efficiency and productivity of a solar still is very low as compared to other distillation processes, hence it is necessary to enhance the productivity of solar still by improving the conventional design parameters and operational procedures.

The construction of a solar still is very simple. Local people using locally available material can make it. Still is an airtight black painted rectangular basin enclosed by transparent cover to trap the solar energy inside it and contains impure water. When sun light falls on transparent cover, basin water is heated and gets evaporated. The water vapor condenses on the inner side of the

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Nomenclatures

A_b	Basin liner surface area of still (m^2)
A_s	Basin side wall area of still (m^2)
C_w	Specific heat of water in solar still (J/kg °C)
C_i	Specific heat of insulation in still (J/kg °C)
d_w	Water depth in basin (m)
h_{cwg}	Convective heat transfer coefficient from basin water to glass cover (W/m^2 °C)
h_{ewg}	Evaporative heat transfer coefficient from basin water to glass cover (W/m^2 °C)
h_{rwg}	Radiative heat transfer coefficient from basin water to glass cover (W/m^2 °C)
h_{twg}	Total heat transfer coefficient from basin water to glass cover (W/m^2 °C)
h_{cga}	Convective heat transfer coefficient from glass cover to ambient (W/m^2 °C)
h_{rga}	Radiative heat transfer coefficient from glass cover to ambient (W/m^2 °C)
h_{tga}	Total heat transfer coefficient from glass cover to ambient (W/m^2 °C)
h_{cbw}	Convective heat transfer coefficient from basin liner to water (W/m^2 °C)
h_{tba}	Total heat transfer coefficient from basin liner to ambient (W/m^2 °C)
h_{ba}	Total heat transfer coefficient from bottom of basin to ambient (W/m^2 °C)
h_{cba}	Convective heat transfer coefficient from bottom of basin to ambient (W/m^2 °C)
h_{rba}	Radiative heat transfer coefficient from bottom of basin to ambient (W/m^2 °C)
$I(t)$	Solar Intensity (W/m^2)
K_i	Thermal conductivity of insulation (W/m°C)
L_{ev}	Latent heat of vaporization of water (J/kg)
L_i	Thickness of insulation (m)
m_w	Mass of water in basin (Kg)
M_w	Hourly distillate output per unit basin area (Kg/m^2/h)
M'_w	Daily distillate output per unit basin area (Kg/m^2/d)
p_w	Partial saturated vapor pressure at a basin water temperature (N/m^2)
P_g	Partial saturated vapor pressures at glass cover temperature (N/m^2)
q_{cwg}	Convective heat transfer from basin water to glass cover (W/m^2)
q_{ewg}	Evaporative heat transfer from basin water to glass cover (W/m^2)
q_{rwg}	Radiative heat transfer from basin water to glass cover (W/m^2)
q_{twg}	Total heat transfer from basin water to glass cover (W/m^2)
q_{cga}	Convective heat transfer from glass cover to ambient (W/m^2)
q_{rga}	Radiative heat transfer from glass cover to ambient (W/m^2)
q_{tga}	Total heat transfer from glass cover to ambient (W/m^2)
q_{cbw}	Convective heat transfer from basin liner to water (W/m^2)
q_{tba}	Total heat transfer from basin liner to ambient (W/m^2)
q_{ba}	Total heat transfer from bottom of basin to ambient (W/m^2)
q_{cba}	Convective heat transfer from bottom of basin to ambient (W/m^2)
q_{rba}	Radiative heat transfer from bottom of basin to ambient (W/m^2)
R_g	Reflectivity of glass cover
R_w	Reflectivity of basin water
R_g	Reflectivity of basin liner
t	Time interval (s)
t_g	Glass cover thickness (m)
T_g	Glass cover temperature (°C)
T_w	Basin water temperature (°C)
T_b	Basin liner temperature (°C)
T_a	Ambient temperature (°C)
T_{sky}	Sky temperature (°C)
U_b	Overall bottom heat transfer coefficient from bottom to ambient (W/m^2 °C)
U_t	Overall top heat transfer coefficient from basin water to ambient (W/m^2 °C)
U_L	Overall heat transfer coefficient for still (W/m^2 °C)
V_w	Velocity of Wind (m/s)

Greek symbols

α_g	Absorptivity of glass cover
α_w	Absorptivity of basin water
α_b	Absorptivity of basin liner
α'_g	Fraction of solar flux absorbed by a glass cover
α'_w	Fraction of solar flux absorbed by basin water
α'_b	Fraction of solar flux absorbed by basin liner
ε_g	Emissivity of glass cover
ε_w	Emissivity of basin water
ε_b	Emissivity of basin liner
ε_{eff}	Effective emissivity between water surface and glass cover
σ	Stefan–Boltzmann constant
μ_j	Fraction of solar flux having extinction coefficient
η_j	Extinction coefficient
η	Efficiency of solar still

Subscripts

a	Ambient
g	Glass cover
w	Basin water
b	Basin liner

cover and runs down along the cover surface due to gravity and gets collected gradually in a beaker through condensate channel.

Various improved designs and modifications of a solar still have been made by several researchers all over the world to make the features attractive, improve the performance, feasibility and adaptability. A number of theoretical studies were also conducted. Dunkle [1] presented the heat equations of heat and mass transfer relations and empirical relations of convective and evaporative heat transfer coefficient for a single basin solar still. The calculation of glass cover temperature for a given ambient and basin water temperature was done using heat balance equations with the help of trial and error method. Lof et al. [2] analyzed the climatic and operational parameters on the various designs of solar still for improving the working and productivity. Morse and Read [3] developed the graphical method for determining the performance of a solar still by means of characteristic chart. Cooper [4,5] determined the maximum efficiency of single effect, horizontal solar stills and investigated the various parameters of still under transient operation with greenhouse effect by simulation technique. Experiments were carried out on the output of a solar still by using different dyes by Sodha et al. [6]. It was found

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