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Performance analysis of single basin solar distillation cum drying unit with parabolic reflector

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ABSTRACT

In this communication, it is attempted to utilize the heat losses from the basin of a distillation unit for drying ginger in a drying chamber attached underneath the distillation unit. Experimentation has been made on single slope single basin solar distillation-cum-drying unit with parabolic reflector. Thermal performance of distillation and drying units is studied at varying water depths in the distillation unit. Based on the experimental data, heat transfer coefficients are evaluated by using linear regression analysis. Average convective heat transfer coefficients have been observed as 5.75 and 4.8 W/m^2 °C for distillation and 3.64 and 2.9 W/m^2 °C for ginger drying at a water depth of 4 cm and 6 cm. Evaporative and radiative heat transfer coefficients for distillation are observed to increase with the increase of solar radiation and ambient temperature. Average 2 l/m^2 distillate and 2 kg/m^2 dried ginger is obtained from the system at 4 cm water depth with an estimated cost of Rs. 2.55 per litre of distillate and per kg of dried ginger. Overall energy and exergy efficiency of solar distillation is found higher at lower water depth. Experimental error for solar distillation and ginger drying is also evaluated in terms of percent uncertainty.

1. Introduction

Utilization of renewable energy sources are the need of present era. Increasing demand and price hiking of energy, depletion of fossil fuels and their harmful effect on the environment and humankind makes the researchers to think on exploring the renewable energy sources mainly the solar energy for various application of life. Solar energy is clean, abundantly available and most accessible natural resource all over the world. It is a natural gift to the countries which lie on the solar belt. Along with energy, lacking of fresh water is also one of the hindrances in the socioeconomic development of a nation. Impure water is the reason for millions of death and many incurable diseases. Many researchers pointed out the need of fresh water along with renewable energy integrated water purification techniques [1–3]. Solar distillation is a thermal energy based technique used for the removal of contaminants from brackish/impure water using solar energy. Depending on the way of harnessing the solar energy, solar distillation technique is classified into two ways, namely, passive solar distillation and active solar distillation. Passive solar distillation technique uses direct solar energy for its operation whereas active solar distillation utilizes some external thermal energy sources (thermal collector, photovoltaic panels, hybrid system, etc.) along with direct solar radiation for the process to be carried out [4]. Different designs of solar distillation (single slope, double slope, inclined, inverted type, wick type, hemispherical, pyramidal, triangular, concave shape, tubular, multi-effect, multi-stage, etc.) have been tested at different meteorological conditions with various operational parameters worldwide. Main drawback of solar distillation technique has been found to be its lower distillate output and lower thermal efficiency. Enormous research work has been carried out on solar distillation technique to improve its performance. Several researchers discussed different parameters affecting the performance of solar still along with improvement techniques. Water depth, large heat losses from the distillation unit (basin and side wall heat losses) and scattered solar radiation are observed to be the important factors for lower productivity and lower thermal efficiency of solar distillation. Different thermal energy storage/phase change materials are used to store the heat dissipated from the bottom of solar still and utilizing that for night hours to increase the yield. Also internal and external reflectors, concentrators, are used to focus the scattered solar radiation on solar stills to improve its performance [5–12].

Radhwan [13] analyzed the transient performance of stepped solar still with built in phase change material. The efficiency of the still was observed to be increased by 57% with a total daily yield of 4.6 l/m^2. El-Sebaii et al. [14] investigated the thermal performance of single slope-single basin solar still with different mass of phase change material (PCM). Daytime productivity of still was observed to decrease with the

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Nomenclature

A_g	Area of ginger drying tray, m^2
A_b	Area of basin tray, m^2
C	Experimental constant
C_v	Specific heat of humid air, J/kg °C
g	Acceleration due to gravity, m/s^2
Gr	Grash of number $= \beta g X_c^3 \rho_v \Delta T/\mu_v$
h_c	Convective heat transfer coefficient, W/m^2 °C
h_{cwo}	Convective heat transfer coefficient for solar distillation, W/m^2 °C
$h_{cw,av}$	Convective heat transfer coefficient for solar distillation, W/m^2 °C
h_{cg}	Convective heat transfer coefficient for ginger drying, W/m^2 °C
$h_{cg,av}$	Average convective heat transfer coefficient for ginger drying, W/m^2 °C
h_{ew}	Evaporative heat transfer coefficient for solar distillation, W/m^2 °C
$h_{ew,av}$	Average evaporative heat transfer coefficient for solar distillation, W/m^2 °C
h_{rw}	Radiative heat transfer coefficient for solar distillation, W/m^2°C
K_v	Thermal conductivity of humid air, W/m °C
m_{ei}	Mass evaporated, kg
m_{ew}	Mass of distillate collected, kg
M_d	Mass of ginger dried per batch, kg
D	Number of days dryer works per year
D_b	Number of drying days per batch (3 for ginger drying for developed unit)
n	Experimental constant
Nu	Nusselt number $= h_c X_c/K_v$
Pr	Prandtl number $= \mu_v C_v/K_v$
$P(T)$	Partial vapor pressure at temperature T, N/m^2
P_w	Partial saturated vapor pressure at water temperature, N/m^2
P_{ci}	Partial saturated vapor pressure at condensing cover temperature, N/m^2
Q_e	Rate of heat utilized to evaporate moisture, J/m^2 s
T_{ci}	Inner glass cover temperature, °C
T_v	above water surface temperature, °C
T_w	water temperature, °C
T_g	Temperature of ginger surface, °C
T_e	Temperature just above the ginger surface, °C
T_a	Ambient Temperature, °C
X_c	Characteristic dimension, m
ΔT	Effective temperature difference, °C
t	Time, s
N	Number of observation in each set
N_o	Number of sets
X	Observations
$\overline{X}$	Mean of total observations
$I(t)$	Solar intensity per hour, W/m^2
Ex_{in}	Exergy input

Greek symbols

β	Coefficient of volumetric expansion, (K^{-1})
γ	Relative humidity, (%)
λ_i	Latent heat of vaporization, J/kg
λ_g	Latent heat of vaporization for ginger drying, J/kg
λ_w	Latent heat of vaporization for distillation, J/kg
μ_v	Dynamic viscosity of humid air, Ns/m^2
ρ_v	Density of humid air, kg/m^3
ε_{eff}	Effective emissivity
ε_w	Emissivity of water
ε_g	Emissivity of glass
σ_s	Stefan Boltzman constant
σ	Standard deviation
η_t	Overall thermal efficiency of still
η_{ex}	Exergy efficiency of still

increased mass of PCM, but the overall productivity was increased. Tabrizi and Sharak [15] experimentally studied the performance of basin solar still integrated with a sandy heat reservoir. With the use of heat reservoir, total yield was observed to increase by 75% than conventional solar still. Tabrizi et al. [16] investigated the performance of weir type cascade solar still at different flow rates and with and without use of PCM. Solar still performance without PCM was observed higher than the still with PCM in sunny days and reverse was observed in cloudy days. In sunny days, maximum distillate of 4.85 and 5.14 kg/m^2 was observed at a minimum flow rate of 0.055 kg/min for the designed solar still with and without PCM respectively. Dashtban and Tabrizi [17] studied the performance of weir type cascade solar still with and without PCM. Effect of water level on the absorber plate and distance between water and glass surface on the performance of the still was investigated. The productivity of the still was observed to increase by reducing the water level and air gap in the still. With the use of PCM, still gave 31% higher yield than the still without PCM. Ansari et al. [18] numerically investigated the influence of three kinds of PCM of a different melting point on passive solar still performance. It was concluded from the result that PCM increases the efficiency of the system and choice of PCM was in accordance with basin water temperature. Sathyamurthy et al. [19] studied the effect of heat storage material on the performance of triangular pyramid solar still. Paraffin wax was used as storage material and observed that productivity increases up to 35% in comparison to still without storage. Arjunan et al. [20] studied the effect of different energy storage materials on the performance of a single slope single basin solar still. Use of energy storage material is concluded as low cost improvement modification in solar still. Sharshir et al. [21] modified a conventional solar still using flake graphite nanoparticle (FGN), phase change material (PCM) and film cooling on it. The effect of water depth on the performance of modified solar still have also been carried out. The modified solar still shows improvement of 73.8% in productivity due to increase in water temperature using FGN and PCM and higher water-glass temperature difference by glass cover cooling. Sahota et al. [22] analyzed the energy matrices, enviroeconomic and exergoeconomic of passive double slope solar still (PDSSS) incorporated with water based metallic nanoparticles (Al_2O_3, TiO_2 and CuO). Annual productivity, energy and exergy efficiency of the PDSSS system increases nearly 19.10%, 26.76% and 37.77% respectively using Al_2O_3 nanofluid.

Badran and Abu-Khader [23] studied the effect of insulation thickness and other effective parameters on the thermal performance of single slope solar still. Efficiency of the system was observed directly related with insulation thickness. Sahoo et al. [24] experimentally investigated the performance (removal of fluoride contaminants from drinking water) and efficiency of solar still using blackened basin surface and thermocol insulation. Reduction of 92–96% fluoride from sample water and an increase of 4.69% and 6.05% in efficiency were observed using blackened basin liner and blackened basin liner with bottom and side thermocol insulation. Srivastava and Agrawal [25] experimentally investigated the effect of water depth and base and side insulation on the performance of single sloped basin solar still integrated with porous fins. Maximum distillate of 7.5 l/m^2 was observed from the modified still in the month of May. Better perfor-