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# Energy matrices, exergoeconomic and enviroeconomic analysis of modified multi–wick basin type double slope solar still

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ABSTRACT

The present study is devoted to developing a thermal model of modified multi–wick basin type double slope solar still (MMWBDSSS). Analytical expressions of temperatures of water, wick, walls, and glass covers, distillate yield and instantaneous efficiency have been derived. The experimental validation of thermal model has been carried out and a fair agreement has been detected between theoretical results and experimental observations. On the basis of annual energy and exergy, the energy matrices, namely, the energy payback time (EPBT); life cycle conversion efficiency (LCCE); energy production factor (EPF), enviroeconomic and exergoeconomic analysis has also been evaluated for the solar still with jute and black cotton wicks under the climatic conditions of Allahabad, Uttar Pradesh (U.P.), India. The $CO_2$ emission mitigated per annum has been found to be 7.82 and 8.69 tons on energy basis; and 0.155 and 0.198 tons on exergy basis with jute and black cotton wicks at 1 cm water depth, respectively. The exergoeconomic parameter has been found to be 0.0623 kWh/Rs. and 0.0791 kWh/Rs. for the solar still with jute and black cotton wicks at 1 cm water depth, respectively for 4% interest rate and 50 years life span of the system.

## 1. Introduction

Water scarcity has become a worldwide critical issue in most of the territories of the globe in last four–five decades. Rapid industrialization and economic development, exponential population growth, over–-exploitation of forest resources brought up serious consequences for the mankind. A nearly 97.5% of the water body is covered by seawater, potable water only constitutes 0.014% of total available water on earth [1]. About 60% of the globe's population will face water shortage by the year 2025 due to excessive use of natural and groundwater resources which is primarily a source of potable or drinkable water [2]. Conventional desalination technologies are available for purifying the water, but due to high energy intensive and dependent on fossils fuels, carbon emission to the environment degrade ecology and natural habitats [3].

Therefore, finding renewable and sustainable energy technology, which is cost–effective, safe, environmentally friendly to produce potable water from unkempt or toxic water for its optimal use in drinking and other purposes is utmost necessary. Solar thermal energy based solar distillation looks promising and one of the recognized renewable source for distilling brackish water in remote, arid, local and rural regions with near zero emission of carbon to the environment. The solar distillation occurred in a house type structure called solar still. Solar still further categorize into (i) passive solar stills, and (ii) active solar stills. Many researchers have worked on different designs and configurations of passive solar stills to increase the distillate yield and overall performance such as: double effect solar distiller [4], hemispherical solar distiller [5], triangular solar still [6], double basin double slope solar distiller [7], effect of air flow on 'V' type solar distiller [8], conical solar still [9], stepped solar distiller [10], weir–type cascade solar distiller with energy storage system [11], tubular solar still [12–14], point–focus parabolic solar still [15], portable solar still with thermoelectric module [16,17], single basin fin–type solar still [18,19], solar still with corrugated absorbers [20], solar distiller with internal and external reflectors [21,22], effect of air motion inside the solar still [23,24]. Rufuss et al. [25] summarized a detailed review in focus of active; passive; and multi–effect solar stills, described the modifications for enhancing the distillate output using fins, heat storage systems, condensers and stated optimization schemes for increasing the heat and mass transfer rates inside the solar distillers. Many studies have

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## Nomenclature

| | |
|---|---|
| $A_b$ | Basin area ($m^2$) |
| $A_E$ | East wall area ($m^2$) |
| $A_{Eg}$ | East glass cover area ($m^2$) |
| $A_N$ | North wall area ($m^2$) |
| $A_S$ | South wall area ($m^2$) |
| $A_W$ | West wall area ($m^2$) |
| $A_{Wg}$ | West glass cover area ($m^2$) |
| $C$ | Specific heat of water (J/Kg–K) |
| $\frac{dT_w}{dt}$ | Change in the water temperature in small time $dt$ |
| $E_{in}$ | Embodied energy (kWh) |
| $E_{ex,\ ann}$ | Annual exergy gain (kWh) |
| $E_{out,\ ann}$ | Annual solar energy output (kWh) |
| $E_{sol(en),\ ann}$ | Annual solar energy retrieved by the solar still (kWh) |
| $E_{sol(ex),\ ann}$ | Annual solar exergy of the solar still (kWh) |
| $Ex$ | Exergy (kWh) |
| $h_{acro}$ | Overall heat transfer coefficient from inner surface of acrylic wall to ambient ($W/m^2$–K) |
| $h_{ba}$ | Heat transfer coefficient from basin to ambient air ($W/m^2$–K) |
| $h_{bw}$ | Heat transfer coefficient from basin to water ($W/m^2$–K) |
| $h_{FRPo}$ | Overall heat transfer coefficient from inner surface of FRP wall to ambient ($W/m^2$–K) |
| $h_{go}$ | Overall heat transfer coefficient from inner surface of glass cover to ambient ($W/m^2$–K) |
| $h_{Kacr}$ | Conductive heat transfer coefficient of acrylic wall ($W/m^2$–K) |
| $h_{KFRP}$ | Conductive heat transfer coefficient of FRP wall ($W/m^2$–K) |
| $h_{Kg}$ | Conductive heat transfer coefficient of glass cover ($W/m^2$–K) |
| $h_o$ | Convective radiative heat transfer coefficient from outer surface of glass cover to ambient ($W/m^2$–K) |
| $h_s$ | Heat transfer coefficient of side wall ($W/m^2$–K) |
| $h_{NV}$ | Total internal heat transfer coefficient from north wall to vapor ($W/m^2$–K) |
| $h_{VE}$ | Total internal heat transfer coefficient from vapor to east wall ($W/m^2$–K) |
| $h_{VEg}$ | Total internal heat transfer coefficient from vapor to east glass cover ($W/m^2$–K) |
| $h_{VS}$ | Total internal heat transfer coefficient from vapor to south wall ($W/m^2$–K) |
| $h_{VW}$ | Total internal heat transfer coefficient from vapor to west wall ($W/m^2$–K) |
| $h_{VWg}$ | Total internal heat transfer coefficient from vapor to west glass cover ($W/m^2$–K) |
| $h_{w-wick(E)}$ | Heat transfer coefficient for east wick ($W/m^2$–K) |
| $h_{w-wick(W)}$ | Heat transfer coefficient for west wick ($W/m^2$–K) |
| $i$ | Interest rate (%) |
| $I(t)_{input}$ | Total heat input to the solar still (W) |
| $I_E(t)$ | Solar intensity on east wall ($W/m^2$) |
| $I_{Eg}(t)$ | Solar intensity on east glass cover ($W/m^2$) |
| $I_{Ng}(t)$ | Solar intensity on north wall through glass covers ($W/m^2$) |
| $I_S(t)$ | Solar intensity on south wall ($W/m^2$) |
| $I_W(t)$ | Solar intensity on west wall ($W/m^2$) |
| $I_{Wg}(t)$ | Solar intensity on west glass cover ($W/m^2$) |
| $k_{acr}$ | Thermal conductivity of Acrylic (W/m−K) |
| $k_{FRP}$ | Thermal conductivity of FRP (W/m−K) |
| $k_g$ | Thermal conductivity of glass cover (W/m−K) |
| $L_{vap}$ | Latent heat of vaporization (J/Kg) |
| $l_{acr}$ | Thickness of Acrylic sheet (m) |
| $l_{FRP}$ | Thickness of FRP sheet (m) |
| $l_g$ | Thickness of glass cover (m) |
| $M$ | Mass of water (Kg) |
| $\dot{M}_{eEg}$ | Hourly yield retrieved from east glass cover (ml) |
| $\dot{M}_{eS}$ | Hourly yield retrieved from south wall (ml) |
| $\dot{M}_{eWg}$ | Hourly yield retrieved from west glass cover (ml) |
| $\dot{M}_{ew}$ | Total hourly yield of the solar still (ml) |
| $M_s$ | Maintenance cost (Rs./year) |
| $\dot{M}_{total}$ | Total daily yield of the solar still (ml) |
| $n$ | Life span of solar still in years (y) |
| $R_{ex}$ | Exergoeconomic parameter |
| $SV$ | Salvage value (Rs.) |
| $t$ | Time (h or s) |
| $T_a$ | Ambient temperature (°C) |
| $T_b$ | Basin temperature (°C) |
| $T_w$ | Water temperature (°C) |
| $T_{w-wick(avg.)}$ | Average temperature of strap layer of water–wick spread on east and west side (°C) |
| $T_{w-wick(E)}$ | Temperature of water in east side wick (°C) |
| $T_{w-wick(W)}$ | Temperature of water in west side wick (°C) |
| $T_V$ | Vapor temperature (°C) |
| $v$ | Wind velocity (m/s) |

*Greek*

| | |
|---|---|
| $\alpha'_b$ | Solar flux absorption factor for basin |
| $\alpha'_E$ | Solar flux absorption factor for east wall |
| $\alpha'_g$ | Solar flux absorption factor for glass cover |
| $\alpha'_{Ng}$ | Solar flux absorption factor for north wall through glass cover |
| $\alpha'_S$ | Solar flux absorption factor for south wall |
| $\alpha'_W$ | Solar flux absorption factor for west wall |
| $\alpha'_w$ | Solar flux absorption factor for water |
| $\varepsilon_{acr}$ | Emissivity of acrylic wall |
| $\varepsilon_g$ | Emissivity of glass cover |
| $\varepsilon_w$ | Emissivity of water |
| $\theta$ | Inclination angle of glass cover (degree) |
| $\sigma$ | Stephan–Boltzmann constant ($W/m^2$–$K^4$) |
| $\beta$ | Packing factor |
| $\eta_{ex}$ | Instantaneous exergy efficiency (hourly basis) |
| $\eta_i$ | Instantaneous thermal energy efficiency (hourly basis) |
| $\eta_O$ | Overall thermal efficiency of the solar still |
| $dt$ | Small time interval (second) |

*Subscripts*

| | |
|---|---|
| a | Ambient |
| b | Basin |
| conv | Convection |
| E | East side |
| eff | Effective |
| en | Energy |
| ex | Exergy |
| exp. | experimental |
| e, evap | Evaporation |
| g | Glass cover |
| ins | instantaneous |
| i, insurf | Inner surface |
| N | North side |
| o | Outer |
| rad | Radiation |
| S | South side |
| theo | theoretical |
| V | Vapor |
| w | Water |
| W | West side |
| w–wick | Strap layer of water–wick |