Solar Energy 155 (2017) 829–846

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

# Energy, exergy and cost analyses of N identical evacuated tubular collectors integrated basin type solar stills: A comparative study

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ARTICLE INFO

*Article history:*
Received 20 February 2017
Received in revised form 2 July 2017
Accepted 6 July 2017

*Keywords:*
Energy
Exergy
Cost
ETC
Solar still

ABSTRACT

This paper deals with the comparative study of basin type solar stills incorporated with N identical evacuated tubular collectors on the basis of overall energy and exergy for the same basin area under similar climatic condition. In this work, the optimum number of collectors and mass flow rate has been computed followed by the evaluation of annual production of potable water, energy, exergy and production cost of potable water for the proposed systems at 0.14 m water depth for the complex climatic condition of New Delhi. It is inferred that the value of annual energy is higher by 6.85%; annual exergy is higher by 12.30% and production cost of potable water is lower by 15.19% for double slope solar still integrated with N identical evacuated tubular collectors than similar single slope set up. The proposed systems can be used on commercial scale for providing potable water.

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## 1. Introduction

The contemporary problem of potable water crisis in remote areas can be curtailed with the help of proposed active solar still in which a number of evacuated tubular collectors have been used for providing external heat to the basin. The main advantage of using evacuated tubular collectors is that the loss due convection does not take place as vacuum is present in between tubes. Rai and Tiwari (1983) investigated active solar still in forced mode theoretically for the first time and concluded that the daily yield of active solar still was higher by 24% than conventional solar still. In unison, Zaki et al. (1983) studied the active solar still under natural circulation mode for the first time and concluded that the maximum enhancement in distillate output was 33% higher in comparison to conventional solar still. Solar still can be integrated with a number of series connected flat plate collectors (FPC) to form a closed loop so that hot water can be discharged either directly or indirectly by providing heat exchanger in the basin. Single slope solar still (SS) included with inverted absorber asymmetric line-axis compound parabolic concentrator collector (CPC) was investigated by Yadav and Yadav (2004) and they concluded that the production of potable water was improved as compared to conventional solar still because solar energy was provided to solar still both from top and bottom concurrently ensuing in enhanced temperature difference between water surface and glass cover. An experimental investigation of solar still having mirrors at interior walls and coupled with FPC was done by Badran and Al-Tahaineh (2004). They observed an enhancement in distillate output by 36% as compared to conventional solar still. It happened due to enhanced temperature difference between water surface and inner surface of glass cover.

Abdel-Rehim and Lasheen, 2007 studied basin type SS by integrating solar parabolic trough collector and heat exchanger. Oil was used as working fluid in collector. The amount of distillate output obtained from such system was 18% higher as compared to conventional solar still because of the attainment of higher water temperature in basin as water received solar energy from top and also through heat exchanger in basin. Tripathi and Tiwari (2005) explored experimentally basin type SS included with two collectors and operating in forced mode. They concluded that higher production of potable water was obtained during off-sunshine hours due to heat storage effect at higher depth. Badran et al. (2005) explored basin type solar still (double slope) which was included with FPC and operating in forced mode. They concluded that the production of potable water was higher by 52% as compared to conventional solar still. Taghvaei et al. (2014) studied experimentally SS coupled with FPC to assess the long term performance (continuous 10 days) and recommended a higher depth of water for practical application as the amount of potable water production and efficiency were found to be higher at higher depth due to heat storage effect.

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http://dx.doi.org/10.1016/j.solener.2017.07.018
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**Nomenclature**

| | |
|---|---|
| $A_b$ | area of basin, $m^2$ |
| $A_g$ | area of glass cover, $m^2$ |
| $a$ | clear day (blue sky) |
| $b$ | hazy day (fully) |
| $c$ | hazy and cloudy (partially) |
| C | specific heat capacity, J/kg-K |
| $C_{solar\ still}$ | cost of solar still, Rs. |
| $C_{ETC}$ | cost of ETC, Rs. |
| $C_{fab}$ | fabrication cost, Rs. |
| $C_{wp}$ | production cost of water, Rs./kg |
| $d$ | cloudy day (fully) |
| SS | single slope solar still |
| ETC | evacuated tubular collector |
| $E_{out}$ | annual energy output, kWh |
| FF | fill factor, dimensionless |
| $F_{CR,i,n}$ | capital recover factor, fraction |
| $F_{SR,i,n}$ | sinking fund factor, fraction |
| $F'$ | collector efficiency factor, dimensionless |
| $\dot{G}_{ex}$ | hourly exergy gain, kWh |
| $h_{cwg}$ | convective heat transfer coefficient from water to inner surface of glass cover, $W/m^2$-K |
| $h_{ewg}$ | evaporative heat transfer coefficient from water surface to inner surface of glass cover, $W/m^2$-K |
| $h_c$ | convective heat transfer coefficient, $W/m^2$-K |
| $h_{ba}$ | heat transfer coefficient from blackened surface to ambient, $W/m^2$ K |
| $h_{bw}$ | heat transfer coefficient from blackened surface to water mass, $W/m^2$-K |
| $h$ | heat transfer coefficient, $W/m^2$-K |
| $h_{rwg}$ | radiative heat transfer coefficient from water surface to inner surface of glass cover, $W/m^2$-K |
| $h_r$ | radiative heat transfer coefficient, $W/m^2$-K |
| $h_{1w}$ | total heat transfer coefficient from outer surface of glass cover to ambient, $W/m^2$-K |
| $h_{1g}$ | total heat transfer coefficient from water surface to inner glass cover, $W/m^2$-K |
| $I(t)$ | solar intensity on collector, $W/m^2$ |
| $I_S(t)$ | solar intensity on glass cover, $W/m^2$ |
| $I_{SE}(t)$ | solar intensity on east glass cover, $W/m^2$ |
| $I_{SW}(t)$ | solar intensity on west glass cover, $W/m^2$ |
| $i$ | rate of interest |
| K | thermal conductivity, W/m-K |
| $L_g$ | thickness, m |
| L | latent heat, J/kg |
| $L'$ | length, m |
| $\dot{m}_f$ | mass flow rate of fluid/water, kg/s |
| $\dot{m}_{ew}$ | mass of distillate from single slope solar still, kg |
| M | maintenance cost |
| $M_{ew}$ | annual production of potable water |
| N-ETC-SS | single slope solar still included with N identical ETC |
| N-ETC-DS | double slope solar still included with N identical ETC |
| $n'$ | number of days |
| $n$ | life of N-ETC-SS/N-ETC-DS, year |
| $N'$ | number of sunshine hours |
| N | number of collectors |
| $PF_c$ | penalty factor due to the glass covers for the glazed portion |
| $PF_1$ | penalty factor first, dimensionless |
| $PF_2$ | penalty factor second, dimensionless |
| $P_p$ | cost of pump, Rs. |
| $P_s$ | net present cost |
| $\dot{Q}_{u,N}$ | useful energy gain for N identical collector connected in series, kWh |
| $R_{o1}$ | inner radius of outer glass tube of evacuated coaxial glass tube, m |
| $R_{i2}$ | outer radius of inner glass tube of evacuated coaxial glass tube, m |
| $R_{o2}$ | outer radius of outer glass tube of evacuated coaxial glass tube, m |
| $r'$ | radius of copper tube in ETC |
| $R'$ | reflectivity |
| $r$ | ratio of daily diffuse to daily global irradiation |
| $T_{foN}$ | outlet water temperature at the end of Nth water collector, °C |
| $T_a$ | ambient air temperature, °C |
| $T_{gi}$ | glass temperature at inner surface of glass cover, °C |
| T | time, h |
| $T_{wo}$ | water temperature at t = 0, °C |
| $T_w$ | water temperature, °C |
| $U_L$ | overall heat transfer coefficient |
| $UAC$ | uniform end-of-year annual cost, Rs. |
| V | velocity of air, m/s |

*Subscript*

| | |
|---|---|
| E | east |
| W | west |
| SS | single slope active solar still |
| DS | double slope active solar still |
| *eff* | effective |
| *en* | energy |
| *ex* | exergy |
| *f* | fluid |
| *g* | glass |
| *in* | incoming |
| *out* | outgoing |
| *w* | water |

*Greek letters*

| | |
|---|---|
| $\alpha$ | absorptivity (fraction) |
| $\eta$ | efficiency, % |
| $(\alpha\tau)_{eff}$ | product of effective absorptivity and transmissivity |
| $\sigma$ | Stefan-Boltzmann constant, $W/m^2$-$K^4$ |
| $\tau$ | transmissivity |

El-Sebaii et al. (2009) compared the performance of single basin active solar still theoretically between with and without a sensible storage material (sand) and reported that daily productivity of the solar still with storage was 23.8% higher than that when it was used without storage. An experimental study regarding the performance of various designs of active solar still was done by Arslan (2012) under closed cycle mode and he obtained highest overall daily efficiency for the circular box active solar still design. In a variation, Lilian et al. (2014) studied a slowly rotating lightweight hollow drum partially submerged in solar still cavity and reported an improvement of 20–30% in the production of potable water as compared to conventional solar still. However, the production of potable water becomes 60% higher than the conventional solar still if the basin of an FPC integrated solar still is partitioned as reported by Rajaseenivasana et al. (2014). A considerable enhancement in productivity is also obtained if thermal energy is supplied to solar still by circulating heat transfer fluid at its bottom. Hamadou and Abdellatif (2014) reported that doubling the heat transfer fluid rate effected a 9% enhancement in the production of potable water. The relation between production

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