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Life cycle cost analysis of single slope hybrid (PV/T) active solar still

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ABSTRACT

This paper presents the life cycle cost analysis of the single slope passive and hybrid photovoltaic (PV/T) active solar stills, based on the annual performance at 0.05 m water depth. Effects of various parameters, namely interest rate, life of the system and the maintenance cost have been taken into account. The comparative cost of distilled water produced from passive solar still (Rs. 0.70/kg) is found to be less than hybrid (PV/T) active solar still (Rs. 1.93/kg) for 30 years life time of the systems. The payback periods of the passive and hybrid (PV/T) active solar still are estimated to be in the range of 1.1–6.2 years and 3.3–23.9 years, respectively, based on selling price of distilled water in the range of Rs. 10/kg to Rs. 2/kg. The energy payback time (EPBT) has been estimated as 2.9 and 4.7 years, respectively.

1. Introduction

Many developed and developing countries of the world are making sustained efforts to harness the renewable energy resources due to the free availability and faster depletion of conventional energy resources. Also, use of fossil fuels leads to long term environmental problems, such as acid rains and greenhouse effects. Similarly, the heavier problems are encountered with nuclear energy, mainly due to the serious risks it implies to harmful radiations. Under these conditions, there is growing interest for renewable and eco-friendly energy sources such as solar energy. Solar energy is a one of the renewable energy resources and avoids most of the negative impact due to the use of fossil fuels. It has many applications; one of which is solar distillation. Water is one of the most abundant resources on earth, covering about 75% of the earth surface. However, about 97% of it is salt water in the oceans, and about 3% is fresh water. Out of the available fresh water, less than 1% is available for human and animal needs. The total water requirements have been increased over the last years for various reasons and most important one is fast economic development, which has lead to a higher standard of living. Solar distillation is an oldest method to produce potable water from brackish or saline water by utilizing the solar energy as reported by various researchers. It is more economical in the areas receives more solar radiation and better solution to the problem of energy security and climatic change with zero running cost. Conventional solar still uses the greenhouse effect to evaporate the pure form of water from the brackish/salty water. The still acts as a heat trap because of transparent roof to incoming sunlight but opaque to the infrared radiation emitted by the hot water. The passive solar still is one of a conventional design in use since 1842 (built in Chile of 4000 m^2 area). The low distillate yield from passive solar still (2–4 l/m^2 day) is a major barrier in its commercialization. In order to meet the requirement of fresh water rigorous research have been carried out by various scientists on design, fabrication and development of the solar stills for distillation to increase its absorptivity to solar radiation. The various solar stills, such as double-roof stills, diffusion stills, wetted wick stills and coupling of solar stills to the external assisting systems (flat-plate collectors, concentrators, heat pipes and waste-heat sources) have been investigated to improve the performance. Malik et al. [1] have reported that the maximum thermal efficiency of a conventional solar still can be 30%, which further depends on the solar intensity, location, time and weather conditions. Al-Hinai et al. [2] have reported the effect of water depth (0.02–0.30 m) on daily distillate yield and recommended the brine water depth in the range of 0.02–0.06 m for better yield from the passive solar still. El-Sebaii [3] has carried out the parametric study of vertical solar still by computer simulation and found that the daily yield decreases with increase in an air space between absorber and glass cover, possibly due to long path of water vapour to travel.

Monthly performances of the passive and active solar stills have been evaluated by Singh and Tiwari [4] for different Indian climatic conditions. They inferred that an annual yield depends on water depth, condensing cover inclination and collector area. They have reported the maximum annual yield at 28.35° inclination of condensing cover, which is latitude of New Delhi (India).

Photovoltaic–thermal (PV/T) technology refers to the integration of a PV module and conventional solar thermal collector in a single piece of equipment. The rationale behind the hybrid concept

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Nomenclature

CPK	cost of distilled water per kg (Rs./kg)
CF	annual cash flow (Rs.)
$F_{CR,i,n}$	capital recovery factor
$F_{SR,i,n}$	sinking fund factor
$HA_{,Com}$	proposed hybrid active solar still
$HA_{,Exp}$	present (experimental) hybrid active solar still
i	rate of interest, fraction (%)
L	latent heat of vaporization, J/kg
M_s	annual maintenance cost of solar still (%)
M	total maintenance cost (Rs.)
M_{yield}	annual yield (kg)
n	expected life of solar still (year)
n_p	payback period (year)
N	no. of clear day in a month
P	present capital cost of the system (Rs.)
$P_{,Com}$	proposed passive solar still
$P_{,Exp}$	present (experimental) passive solar still
P_p	cost of DC water pump (Rs.)
P_m	annual power generated from PV module (kW h)
P_u	annual power utilized from PV module (kW h)
P_s	net present cost of the solar still (Rs.)
S_s	salvage value of solar still as a fraction of capital cost P_s (Rs.)
$S_{p,elect}$	electricity rate per unit (Rs./kW h)
UA	the uniform end of year annual cost (Rs.)
UA_{net}	net uniform end of year annual cost (Rs.)

Subscripts

Exp	experimental solar still
Com	proposed design solar still

Conversion unit

1$	Rs. 39 in 2006

is that a solar cell converts solar radiation to electrical energy with peak efficiency in the range of 9–12%, depending on specific solar-cell type and thermal energy dissipated for water heating. More than 80% of the solar radiation falling on photovoltaic (PV) cells is not converted to electricity, but either reflected or converted to thermal energy. In view of this, hybrid photovoltaic and thermal (PV/T) collectors are introduced to simultaneously generate electricity and thermal power [5]. Chow [6] has analyzed the PV/T water collector with single glazing in transient conditions, consisting of tubes, in contact with the flat plate, reported an increase of electric efficiency by 2%, and obtained the thermal efficiency of 60% at 0.01 kg/s flow rate of water. Further, Zakharchenko et al. [7] have studied the unglazed hybrid (PV/T) system with suitable thermal contact between the PV module and the collector and reported that the area of module and collector in the PV/T system need not to be equal for higher overall efficiency. To operate the PV module at low temperature, the PV module should be fixed at lower temperature part of the collector (i.e. at the inlet of feed water). The parametric study of different configuration of hybrid (PV/T) air collector has also carried out by Tiwari and Sodha [8]. Kumar and Tiwari [9] have reported that daily yield obtained from hybrid (PV/T) active solar still is 3.5 times of the passive solar still. Tiwari et al. [10] have validated the theoretical and experimental results for photovoltaic (PV) module integrated with air duct for composite climate of India and concluded that an overall thermal efficiency of PV/T system is significantly increased due to utilization of thermal energy from PV module. Recently, Dubey et al. [11] have reported the higher annual average efficiency of glass to glass type PV module with and without air duct as 10.41% and 9.75%, respectively.

The economics of any energy system is essential to understand the cost of production and economic payback period on the investment to reduce the risk of project failure. The life cycle cost analysis of solar still depends on several key variables such as

- initial investment
- rate of interest
- annual distillate yield
- maintenance cost
- life time of solar stills
- production cost of distilled water
- selling price of distilled water
- salvage value of the system, etc.

Tleimat and Howe [12] have reported that the solar distillation plants of capacity less than 200 l/day are more economical than the other type of plants. Mukherjee and Tiwari [13] have carried out the economic analysis of three different types of the solar stills, namely a single slope fiber-reinforced plastic (FRP) still, a double slope FRP solar still and a double slope concrete solar still for Indian climatic conditions. They have concluded the minimum cost of distilled water produced from conventional solar stills. Sinha et al. [14] have carried out the techno-economic analysis on active solar distillation system and solar water heater considering 14 years life of the systems.

It has also inferred from the literatures that the maintenance cost of the solar stills is less and required only to clean the systems as well as filling and collection of yield. Therefore, the cost of distilled water mainly depends on initial investment and interest rate. The various scientists have also studied the life cycle cost analysis of the passive solar still under different climatic conditions. Various researchers have done the economic analysis of the solar still plant in different places and the cost of distilled water obtained is presented in Table 1.

Fath et al. [17] have recommended the acceptable cost of the distilled water for potable use in remote areas, if produce from solar stills at $0.03/L (i.e. Rs. 1.20/kg). Kalogirou [18] has estimated that the 25% of the price of distilled water attributes to the energy cost, if produced using conventional fossil fuel in Cyprus. However, the cost analysis carried out by different researchers as mentioned above concludes that the solar stills can be used to provide fresh water at reasonable cost.

In this paper, annual performance and cost of distilled water produced from newly designed hybrid (PV/T) active and passive

Table 1
Cost of distilled water reported by various investigators.

Cost	Year	Investigators	Size of the plant
$20 m^{-3}	1994	Ghoneyem and Ileri [15]	For large size plant
$2.4 m^{-3}	1995	Madani and Zaki [16]	For 50 m^3/day production capacity using porous basin solar stills
$16.3 m^{-3}	2002	Al-Hinai et al. [2]	Based on distillate yield of 52 weeks using a cluster of 250 simple solar stills.
$30 m^{-3}	2003	Fath et al. [17]	Pyramid shaped solar still