SOLAR DISTILLATION SYSTEMS: THE STATE-OF-THE-ART IN DESIGN DEVELOPMENT AND PERFORMANCE ANALYSIS

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ABSTRACT

A review of recent research that has been undertaken on the design and development of various solar distillation systems is reported. A techno-economic analysis is carried out to measure the cost of effectiveness of various distillation systems.

Novel designs of solar distillation systems utilizing the basic geometry of an inverted absorber asymmetric line axis Compound Parabolic Concentrating (CPC) solar energy collector are reported. It is envisaged that these distillation systems will be more efficient due to the higher temperatures available at the absorbing surface and lower temperatures at the condensing surface.

KEYWORDS

Solar distillation systems; design development; CPC solar distillation systems, techno-economic analysis.

INTRODUCTION

Mahik et al. (1982) have reviewed the design, performance, applications and economic analyses of passive solar distillation systems. Recently Tiwari (1992) has updated that review to cover work on solar distillation till 1992. Based on the updated research work on solar distillation. Systems may be classified into various categories as depicted in table 1. Solar distillation remains an attractive desalination process in less developed countries.

Most of the existing distillation plants do not provide their expected output because of drawbacks in their maintenance.

(i) there is no built-in arrangement for basin cleaning

(ii) there is no provision for removal of any algae formation

(iii) sealant materials used do not prevent vapour leakage through joints/corners, and

(iv) cleaning of the glass cover is not carried out sufficiently frequently.
Table 1  Taxonomy of Solar Distillation Systems

Solar Distillation

<table>
<thead>
<tr>
<th>Passive Distillation</th>
<th>Active Distillation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar still in high operating temperature range (≥ 60°C)</td>
<td>Solar still in normal operating temperature range (≤ 60°C)</td>
</tr>
<tr>
<td>Inverted absorber asymmetric line-axis CPC solar still</td>
<td>Nocturnal Distillation</td>
</tr>
<tr>
<td>Distillation with collector panel</td>
<td></td>
</tr>
<tr>
<td>Conventional solar still</td>
<td>Inclined solar still</td>
</tr>
<tr>
<td>Horizontal basin solar still</td>
<td>Inclined basin effect solar still</td>
</tr>
</tbody>
</table>

DEVELOPMENT OF THE PASSIVE SOLAR STILL

Conventional Solar Still

Carolos Wilson, a Swedish engineer, designed the first conventional solar still, in 1872, in Northern Chile. This device was in operation for about 40 years. Various designs of solar still and their performance have been discussed by Malik et al (1982) these include single and double slope, single as well as double basin, inclined step type, wick type and spherical type solar stills etc. A cross-sectional view of a double slope conventional solar still is shown in Fig.1. Most incident solar radiation is transmitted through a transparent glass cover, part of the radiation is reflected or absorbed by the glass cover. The transmitted radiation is then partially reflected from the water surface with the remainder absorbed by the water mass via the basin liner. Most of the absorbed radiation is transferred to the water mass by convection, the remainder is lost to the atmosphere through the bottom insulation. The water warms and thermal heat exchange take place between the water surface and the glass cover by radiation, convection and evaporation. The evaporated water is condensed on the inner surface of the glass cover releasing its latent heat of vaporisation. The condensed water trickles down the inner surface of the cover under gravity, until it is collected in internal gutters. It is collected via a drainage hole provided at the lower end of the condensing cover.

It has been observed that the performance of a conventional solar still is maximum for minimum water
deepth. In order to achieve this condition, a multiwick solar still was developed in 1979 by Sodha et al (1980).

**FIG. 1 ENERGY FLOW PATTERN IN A CONVENTIONAL SOLAR STILL**

**Multi-wick Solar Still**

Cross-sectional views of single and double slope multiwick fibre re-inforced plastic (FRP) solar stills are shown in Fig 2a and 2b. One end of a jute cloth is dipped into the water and the other end is placed at the top of an inclined plane surface. In order to have a uniform water film over the inclined surface, the lower jute cloth should be spread over the entire length and the other jute cloths reduced in length as shown in fig 2. The number of jute cloths used for a unit depends on the insolation level and the length of the inclined surface. Two solar distillation plants were installed based on the design of single and double slope multiwick solar stills, and were monitored for several years. The performance and economic viability of the system have been reported by Yadav and Tiwari (1987). During operation of these systems, the following observations were recorded.

* The dark dye used to enhance the solar absorption at the cloth, leached after about one month into the excess water accumulated during off-sunshine hours.

* Because of inadequate water in the reservoir the amount of water conveyed by capillary action was insufficient to wet the entire length of the inclined surface.

There problems were solved by designing another double slope multiwick solar still, (Singh, 1993), shown in Fig 3. In this case, the outlet of excess water is connected to the reservoir and hence there is recirculation of hot water, if any, between the reservoir and the inclined surface. It has also been observed that the performance of such a solar still is also improved.

During the operation of the solar distillation unit, it was observed that

(i) the absorptance of the absorber deteriorated due to salt deposition on it

(ii) leakage of vapour occurs from the joints between the glass cover and the vertical wall due to the poor quality of the sealant and

(iii) the deposition of dust on the glass cover reduces the transmittance of the glass cover.
In all the above cases, the condensing surface (glass cover) is also the receiver of the input energy (solar radiation) as well as output energy (condensed water).

All the above problems are solved in a new design of solar still, referred to as the inverted absorber solar still.

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**FIG. 2a** CROSS-SECTIONAL VIEW OF SINGLE SLOPE MULTI-WICK SOLAR STILL

**FIG. 2b** CROSS-SECTIONAL VIEW OF DOUBLE SLOPE MULTI-WICK SOLAR STILL

**FIG. 3** CROSS-SECTIONAL VIEW OF MODIFIED DOUBLE SLOPE MULTI-WICK SOLAR STILL
Inverted Absorber Solar Still

The cross-sectional view of an inverted absorber solar still has been shown in Fig 4. Unlike other passive solar stills the solar radiation is absorbed at the bottom of the solar still and the evaporated water is condensed on the upper part of the solar still which is a basic requirement for maximum yield. Further, the convective thermal losses are also suppressed giving maximum utilization of solar radiation. Several designs of an inverted absorber solar still will be discussed in this section.

(i) An Asymmetric Line-Axis CPC Solar Still

An inverted absorber asymmetric line-axis compound parabolic concentrator (CPC) solar still is shown in Fig 5. The solar radiation is reflected from the secondary reflector after coming through the CPC collector and is finally absorbed at the bottom of the solar still. In this way, the solar radiation is increased at the base of the still depending on the concentration ration of the CPC collector. The concentration ratio is expected to be in the range of 1.5 to 2. Further, there is a provision to cool the condensing surface faster by providing forced air cooling as shown in fig 5.
(ii) Vertical Condensing Surface Distillation Unit

An inverted absorber asymmetric line-axis CPC collector can be employed in a distillation unit as shown in Fig 6. The water flows above the inverted absorber of a CPC collector. After the water is heated, it is allowed to flow on a vertical insulated wall. To ensure uniform flow, the vertical wall may be provided with a porous cloth on it. The water is evaporated and condenses on the condensing surface. The length of vertical wall depends on the flow rate of hot water. The condensation can be allowed to occur on both sides of the walls for faster utilization of heated water for distillation.

![Diagram of Vertical Condensing Surface Distillation Unit](image)

FIG. 6 CROSS-SECTIONAL VIEW OF A VERTICAL CONDENSING SURFACE DISTILLATION UNIT

(iii) Spherical Condensing Surface Distillation Unit

The cross-sectional view of a spherical condensing surface distillation unit is shown in Fig 7. In this case, a circulating air fan will be provided between the water heating unit and the spherical condensing unit. The vapour will be carried away by the fan inside the spherical condensing chamber and will immediately be condensed on its inner surface. There will be rapid heat transfer from the outer surface due to the large surface area.

![Diagram of Spherical Condensing Surface Distillation Unit](image)

FIG. 7 CROSS-SECTIONAL VIEW OF A SPHERICAL CONDENSING SURFACE DISTILLATION UNIT
TECHNO-ECONOMIC ANALYSIS

A simple techno-economic analysis (after Yadav and Tiwari, 1989) of the effectiveness of solar distillation systems considers the capital cost of the system $P$ and the rate of capital recovery $C$. The first annual cost of the system $A$ can be determined by the following formula,

$$A = P \frac{r(1+r)^n}{(1+r)^n-1}$$

where $r$ is the rate of interest and $n$ is the life of the system (years).

The salvage value of the system is considered as the cost of usable materials saved even after the system life is over. The first annual salvage value $V$ can be determined by

$$V = S.F$$

where $F$, a depreciation factor is given by

$$F = \frac{r}{(1+r)^n-1}$$

If $M$ is the annual maintenance cost of the system, then the Total Annual cost is $A + M - V$.

This approach has been employed to assess the cost of distilled water from solar stills in India (Yadav and Tiwari, 1989). Their conclusions were compared with those of Kudish and Gale in Israel (1986) and Nandwani in Costa Rica (1990) by Sinha (1983) and are shown in table 2.

Table 2 Cost Comparison of Distilled Water

<table>
<thead>
<tr>
<th>System</th>
<th>Reference</th>
<th>Place</th>
<th>Cost of the System</th>
<th>Output (l)</th>
<th>Cost of Distillate</th>
<th>Relative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled Environment Agriculture Solar Still</td>
<td>Yadav and Gale (1986)</td>
<td>Israel</td>
<td>$1479.5$</td>
<td>211200</td>
<td>0.72 $/l</td>
<td>37.9</td>
</tr>
<tr>
<td>single and double slope</td>
<td>Handwani (1990)</td>
<td>Limon, Costa Rica</td>
<td>$3396.91$ colones</td>
<td>1948.0</td>
<td>1.77 colones/l</td>
<td>1.2</td>
</tr>
<tr>
<td>single and double slope</td>
<td>Handwani (1990)</td>
<td>San Jose, Costa Rica</td>
<td>$3396.91$ colones</td>
<td>2220.7</td>
<td>1.53 colones/l</td>
<td>1.1</td>
</tr>
<tr>
<td>single and double slope</td>
<td>Handwani (1990)</td>
<td>Taboga, Costa Rica</td>
<td>$3396.91$ colones</td>
<td>2378.2</td>
<td>1.43 colones/l</td>
<td>1.0</td>
</tr>
<tr>
<td>single slope fibre reinforced plate</td>
<td>Yadav and Tiwari (1989)</td>
<td>India</td>
<td>$5283.13$ Rs.</td>
<td>18868.3 Rs.</td>
<td>0.28 Rs/l</td>
<td>1.2</td>
</tr>
<tr>
<td>double slope fibre reinforced plate</td>
<td>Yadav and Tiwari (1989)</td>
<td>India</td>
<td>$6168.26$ Rs.</td>
<td>19897.6 Rs.</td>
<td>0.310 Rs/l</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Note: Fuel price escalation is 0.04
1 US dollar = 75 colones = 12 Rs. (1986)*
CONCLUSIONS

New developments in the design of passive solar distillation units, such as the multi-wick solar still and the asymmetric line-axis CPC solar still should lead to greatly improved system efficiencies over those presently used. Assuming that the new modified designs can be manufactured both cheaply and with locally available materials, solar distillation should provide a simple reliable cost effective option for providing potable water in large areas of the world.

REFERENCES