An overview about influence of wick materials on heat and mass transfer in solar desalination systems

M Murugan¹, A Saravanan², Pramod Kumar¹, V Siva Nagi Reddy¹ and Abdul Arif¹

¹Department of Mechanical Engineering, Aditya College of Engineering & Technology, Surampalem, East Godavari – 533 437, Andhra Pradesh, India.
²Department of Mechanical Engineering, Aditya Engineering College, Surampalem, East Godavari – 533 437, Andhra Pradesh, India.

E-mail: murukar@gmail.com

Abstract. Over ongoing decades, the global demand for potable water is expanding quickly; at the same time, the supply of potable water is restricted due to fast advancement in industrialization, the devastation of trees, less awareness towards the plantation, and population growth. There are numerous freshwater production methods available in this world, in that solar-based still (Solar still) is one of the most normal and least expensive techniques. A lot of examinations have been portrayed experimentally and theoretically on the solar stills for evaluating its performance under different climatic and working environment. Heat and mass transfer are the two key factors that play a vital role in the evaluation of solar still's performance. In this study various experimental and theoretical methodologies that have been utilized to evaluate the heat and mass transfer analysis of solar stills using wick materials are critically reviewed. While looking into consideration, the reviewed articles demonstrate that the efficiency of the solar stills relies upon the various outside and inside working parameters. The result revealed that the wick materials with high porous values are produced better productivity than the low porous wick materials.

Keywords: Single slope, double slope, pyramid solar still, wick material, heat and mass transfer.

1. Introduction

Water is a fundamental requirement for the survival of the living organism in the world. The accessibility of pure and clean water for drinking is the most serious requirement for human beings in most of the regions of the world. At the same time, the wastewater from municipal and industry without appropriate management that caused serious contamination on freshwater sources has forced the issue [1]. The shortage of water firmly confines the financial development of these nations.

To address the water scarcity, an assortment of conventional freshwater production techniques has been considered to produce water for domestic, commercial, and industrial applications which include seawater/salty water, untreated water from civic and industry, polluted river or groundwater, and so on. Coincidently, the regions where the water scarcity is severe are commonly blessed with an enormous amount of intensity of solar energy. This permits the location of water shortage with sustainable solar energy. Reasonable innovations should be created to incorporate solar energy for
treating the contaminated water into potable water. The desalination of water using solar energy have gotten impressive consideration everywhere in the world because of its relevance to dry or remote areas [2-7].

The existing solar-based desalination system has been generally operated by an indirect method. In that method, first the solar energy was transformed into electrical energy and then this electrical energy was used to run the solar desalination system. Later, the solar energy is directly converted to pressure and/or heat energy for desalinating the water. Compared to the indirect method, direct methods have more potential, cost-effective methods, and high energy efficiency [8].

The above literature study [1-8] clearly pointed out that solar-based freshwater production techniques are best when compared to all other techniques. This present study mainly focuses on the use of wick materials to improve the heat and mass transfer rate of various solar stills and also points out the best structural design of solar stills for permitting the researchers to streamline the solar stills for future development.

2. Selection of wick materials
Wick materials are fabrics that can absorb more water and hold the same for a long time. Hence the water in the fabric gets more heat energy when it is exposed to sunlight quickly than the water stagnated in the basin type solar stills. It ensures a better evaporation rate of water. The selection of such kind of wick materials mainly depends upon the special value called "Porosity". The evaluation of porous space exists in the wick material is termed as Porosity. The following relation is used to calculate the porosity of the wick materials as per the suggestion given by Munisamy et al. [9].

\[
\phi = \frac{V_p}{V_{bk}}
\]

Where, \(V_p\) and \(V_{bk}\) are pore volume and bulk volume in \(m^3\) respectively

\[
V_p = \frac{W_w}{\rho_w}
\]

\[
W_w = W_{sat} - W_{dry}
\]

Where, \(W_w\), \(W_{sat}\), and \(W_{dry}\) are the weight of water in pore space, saturated weight, and dry weight in kg respectively. \(\rho_w\) is water density in \(kg/m^3\)

\[
V_{bk} = \text{length} \times \text{breath} \times \text{thickness of wick material}
\]

2.1. Effect of wick materials in Single slope solar stills
Shanmugan [10] has designed and manufactured a single-slope single basin solar still to evaluate the performance using fins attached in the basin which are covered by wick materials. The equations of energy balance have been derived to measure the various parameters. The experimental results concluded that during summer and winter, the average performance of the proposed method was 59.14 percent and 27.13 percent, respectively. The photographic view of the test facility can be seen in the Figure 1.

![Figure 1. Photographic view of experimental arrangement [10]](image-url)
The trial examination has been conducted using various wick materials in a regular single-slope basin type solar still with two different arrangements by Ahmed [11]. Three different configurations of solar stills have been tested under the same working conditions. The conventional still has been taken as first still for comparison. In second on, wick fabric has been spread uniformly wrapped up within the solar still basin surface. While, the last still actually has supported by a unique design of wire mesh as shown in Figure 2. They concluded that the light black cotton fabric has performed better than the other wick materials used in the study. The daily productivity of the second and third still has been improved up to 26.9% and 20.8% compared to the first type of solar still respectively.

Haddad et al. [12] have manufactured an experimental component to examine the impact of utilizing a wick that used to rotate vertically on the freshwater outlet of a regular solar still. Some modifications have been done in the traditional solar still of area 0.36 m² as illustrated in Figure 3. The rotating wick belt of area 0.367 m² has been placed at 10 cm apart from the vertical wall of the still and had a similar capacity to the dark jute material. Moreover, a solar photovoltaic panel has been used to supply power (25W) for the DC motor which rotates the wick material vertically.
The performance analysis of single-slope single-basin solar still has been evaluated experimentally and theoretically by Agarwal and Rana [13]. Several V-shaped floating wicks have been used to maximise the flow of heat and thus improve efficiency. The evaporative surface region of modified solar-powered still is 26 percent higher than that of conventional still due to their V-shaped profile. The outcome showed that daily productivity was observed on clear sunny days at about 6.20 kg/m² and 3.23 kg/m² respectively during summer and winter.

The following equation has been used to calculate the heat transfer between V-shaped floating wick and basin water:

$$Q_{fw-bw} = k_{fw}(T_{fw} - T_{bw})$$

The equation of heat loss between basin water and atmospheric air has been given below:

$$Q_{bw-a} = h_{bw-a}(T_{bw} - T_{a})$$

Where, $k_{fw}$ is heat transfer coefficient of floated wick materials, $T_{fw}$, $T_{bw}$ and $T_{a}$ are temperature of floated wick, basin water, and ambient air respectively.

A theoretical and experimental research has been conducted by Modi and Modi [14] to investigate the effect of the single-slope double-basin solar wick pile of jute cloth. For that, they have constructed two similar experimental setups, one with piles of jute wick fabric on the absorber plate and another one without any wick piles as shown in Figure 4. They have developed the theoretical model to compare the results obtained from the theoretical model with the experimental results. The results revealed that the still with jute wick piles has produced maximum productivity than the still without wick piles by 23.71%.

![Figure 4. Single-slope solar still (a) without (b) with wick pile of jute cloth on absorber plate [14]](image)

2.2. Effect of wick materials in Double slope solar stills

A double slope basin type solar still has been made-up of mild steel plate and has been examined with using various wick fabrics like waste cotton pieces, light cotton cloth, coir mate, and sponge sheet in the basin and with a minimum mass of water by Murugavel and Srithar [15]. They also tested the rectangular aluminium fins that were coated with different wick materials with different configurations as shown in Figure 5. The rectangular aluminium fin covered with a cotton cloth and arranged in the longitudinal direction has been found to be more effective.
Piyush et al. [16] have conducted an experimental study to analyze the performance of double-slope basin type solar still using various wick materials. The test information for various months has been introduced and examined the impact of ambiance and testing conditions on the productivity of modified proposed solar still. The outcome of the result concluded that the maximum yield for the black cotton wick was obtained as 9012 ml / day (4.50 l / m² day) compared to 7040 ml / day (3.52 l / m² day) for the jute wick at 2 cm water depth in the proposed still. Figure 6 also displays the pictorial view of the proposed.

Gnanaraj and Velmurugan [17] have conducted experimental investigations to increase the efficiency of double-slope single basin solar still. This examination pointed toward enhancing the freshwater production of double-slope single basin solar still. Some inside and outside modifications have been done in the conventional solar still. They have tested three different modified stills one with finned ridged basin, another one with black rock, and the final one with a wick. Another still with
outer reflectors (outside alteration) has been additionally manufactured. The maximum daily productivity of 5130 ml/m² has been achieved by the still with modification in both internal and external structure of the still. Followed by this the still with reflectors has produced the maximum yield of 3655 ml/m². The schematic arrangement of various parts of the experimental arrangement is illustrated in Figure 7.

![Schematic arrangement of experimental setup](image)

**Figure 7.** Schematic arrangement of experimental setup [17]

Sharshir et al. [18] performed an experimental study to test energy, exergy, and economic improvement on stepped double slope solar still using nanoparticles and linen wicks. Freshwater productivity and energy efficiency of the proposed solar still with carbon black nanoparticles and linen wicks have been improved by 80.57% and 110.5% respectively, than the conventional solar still. They have suggested calculating the coefficient of convective and evaporative heat transfer as per the equations specified below:

**Coefficient of convective heat transfer between water and glass cover:**

\[ h_{c(w-g)} = 0.884 \left( \frac{T_w - T_g}{268.9 \times 10^{3} - P_w} \right)^{1/3} \]  \( (7) \)

**Coefficient of evaporative heat transfer between water and glass cover:**

\[ h_{ev(w-g)} = 16.273 \times 10^{-3} h_{c(w-g)} \times \frac{P_w - P_g}{T_w - T_g} \]  \( (8) \)

The partial pressure of water \( P_w \) and \( P_g \) at \( T_w \) and \( T_g \) respectively can be calculated as follows

\[ P_w = e^{(25.317 - \frac{5114}{T_w})} \]  \( (9) \)

\[ P_g = e^{(25.317 - \frac{5114}{T_g})} \]  \( (10) \)

Where, \( T_w \) and \( T_g \) are water and glass temperatures, respectively.

### 2.3. Effect of wick materials in Pyramid type solar stills

Kabeel [19] has fabricated a pyramid type solar still with a concave wick surface. This is because the surface of the concave wick has increased the area of evaporation due to capillary action. In this experimentation, 5 cm thick wick material has been used to cover the concave-shaped basin surface. To increase the absorption rate of solar radiation, the wick materials have been coated with black colour. Also, they have tested the performance of the still by the varying depth of water. They
concluded that the average freshwater production per day in the daytime was 4.1 l/m$^2$. In Figure 8, the schematic view of various parts of the solar pyramid still with a concave wick surface is shown.

![Figure 8. Line diagram of pyramid solar still with concave wick surface [19]](image)

A new solar pyramid form wick-type still was developed, manufactured and analysed by Prakash et al. [20] to boost the overall device productivity. The basin of the still has been modified with four inclined portions for storing saline water. In this inclined portion, jute fabric that is coated with selective block paint has been covered. Then the proposed freshwater production was compared with the traditional solar pyramid still without wick material and noted that the productivity increment was 17.68 percent greater than the conventional one.

![Figure 9. Pictorial view of pyramid type tilted-wick type solar still [20]](image)

An experimental study has been conducted on pyramid type solar distiller to enhance the performance using nanofluid incorporated with v-corrugated receiver plate and wick by Sharshir et al. [21]. They have proposed three modification on conventional pyramid type solar still. In first still, they have replaced the flat plate absorber with a v-corrugated absorber to augment the area of evaporation.
Wick materials have been included along with the v-corrugated absorber plate in the second still. In the third still, copper oxide nanofluid has been added in the second modified still. The result revealed that the third modified still has improved the overall efficiency of energy and exergy by 77.9% and 93% respectively, than the conventional one. With the help of various wick materials vertically mounted to the basin surface as shown in Figure 10, the output of the square pyramid solar still (SPSS) was analyzed experimentally by Saravanan and Murugan [22]. The experimental findings showed that the freshwater production of woollen content still proposed was 9.4 percent, 20.9 percent, and 33.1 percent greater than jute fabric, terry cotton material, and polyester, respectively. Figure 11 indicates the photographic arrangement of SPSS.

The hourly productivity \( (m_{ev}) \) and daily efficiency \( (\eta_d) \) of the solar still have been calculated by using the following equations:

\[
m_{ev} = \frac{h_{ew} \times (T_w - T_g) \times 3600}{h_f g}
\]

The daily efficiency,

\[
\eta_d = \frac{Q_{ew}}{I \times A_b}
\]

Figure 10. Schematic view of SPSS with vertical wick [22]

Figure 11. Pictorial arrangement of experimental facility [22]
3. Integration of solar stills with solar collectors

A transient analysis on a single-basin solar type still integrated with a traditional flat plate collector was carried out by Rai and Tiwari [23]. The experimental results showed that distilled water's average daily production was 24% higher than that of a single solar basin without incorporation of a flat plate collector. This is because the integration of solar collectors with the still has raised the initial temperature of the basin water in the still, which raises the evaporation rate.

![Figure 12. Line diagram of single-basin solar still with flat plate collector [23]](image)

Velmurugan et al. [24] have connected a single-basin type solar still with stepped absorber solar still and miniature solar pond for enhancing the performance of the system. They also performed the experiment by replacing the solar single-basin with the solar wick type still. They concluded that the performance of the proposed arrangement has been improved by 78% compared to the performance analyzed individually. Murugan et al. [25] increased the productivity of a solar water distillation system of flat plate wick type by integrating it with V-trough solar water heater. Also, they have proposed the influences of wick material, solar intensity, flow rate, and ambient temperature on productivity. The results revealed that the productivity of the solar still coupled with V-trough solar water heater was 30.12% greater than still without a V-trough solar water heater. The schematic arrangement of the experimental facility is shown in Figure 13. The Nusselt number and Sherwood number values, which are the two dimensionless numbers used in heat and mass transfer operations, were predicted using the following equations, respectively.

\[
N_u = \frac{h c (w - g)}{k}
\]

Where, \(k\) is the thermal conductivity of vapour which can be calculated as follows

\[
k = 0.0244 + 0.7673 \times 10^{-4} T_v
\]

\[
Sh = \frac{h m}{D}
\]

Where, \(D\) is the mass diffusion coefficient of vapour which can be evaluated as follows

\[
D = 2.31 \times 10^{-3} \frac{P_a}{P_a + P_v} \left(\frac{T_v}{273.16}\right)^{1.81}
\]
4. Conclusion

Desalination of brackish or saline water to get potable water using solar energy is the simplest and economical method due to its simple construction and eco-friendly to the environment. The performance of the solar still can be increased by increasing the evaporation rate and by minimizing the losses in still. Even though lot of examinations are portrayed experimentally and theoretically on the solar stills to improve its performance under various climatic and working conditions, the use of wick materials in the absorber area plays vital role in the improvement of freshwater productivity. Hence in this present study, an effort has been prepared to review the effect of wick materials on heat and mass transfer of various basin type solar stills like single slope, double slope and pyramid shaped stills. Some of the main findings are summarized below.

- Irrespective of the type of stills, the use of wick materials has improved the productivity of the stills compared to the stills without wick materials.
- The wick materials which are having high porous values have performed better than the low porous wick materials.
- Nusselt number and Sherwood number which are the two dimensionless numbers have been involved in the prediction of heat transfer and mass transfer rate respectively.
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