Performance of Various Wick Materials (Cotton, Jute, Wool, Polyester, Terri Cot) in Inclined Slope Solar Still

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Abstract: In this work the effect of different wick materials on the distillate output produced by inclined wick solar still has been experimentally investigated. The wick materials considered are cotton cloth, jute cloth, wool cloth, polyester and terrycloth. Wicking properties of materials such as porosity and capillary rise of water has been experimentally determined. Porosity is maximum 27.9% for cotton wick and minimum 18.9% for jute wick. The rise of water (capillary rise) for cotton wick is 120mm/h. The daily distillate output for solar still containing different wick materials have been experimentally determined in the climate of Raipur, Chattisgarh, India. The daily distillate output produced is maximum 4.321L/m^2 for cotton wick material and minimum 3.156L/m^2 for polyester wick material. The use of cotton wick in solar still is found economical and reliable.

1. Introduction

Both the continuation of human life and socioeconomic progress depend on water. Even yet, there are only a few places where you can get water that is up to par. Water quality can be enhanced by means of desalination. Traditional desalination methods include accessible; however, they demand a significant energy input, primarily from fossil fuels which contribute to the destruction of the environment. Consequently, utilising solar energy is one way to use sustainable energy sources. being one of the more viable options. Technology for desalination is gaining popularity as a reliable technology for fresh generation of water. Literature contains a history of desalination review. Desalination is the procedure used to remove water with a lot of salt, minerals and living things derived from water. Systems for desalinating water require energy to separate the salt from the water [1]. Systems that use solar radiation to separate water and salt are known as solar desalination systems.

Solar desalination is categorised differently based on the methods and energy source. The solar still is the most prevalent form of solar desalination system. Simple equipment called a solar still can be used to turn brackish, salty water into drinkable water. The two main categories of solar still are passive and active. The two main categories of passive stills are inclined and basin kinds. The productivity of these stills was greatly improved by extensive investigation. Water pours from the top to the bottom of the absorber surface in an inclined still. The employment of a wick, which draws water through the capillary action, helps to maintain the consistency of the water's thickness. According to reports, inclined absorber surface stills are much more productive than basin-style stills [2]. The performance of an inclined wick type solar still has been improved by a number of literary works. Ho-Ming Yeh et al. [3] investigation looked at the productivity of wick-type solar distillers in relation to environmental, design, and operational factors. In order to create a new type of still, Minasian et al. [4] joined a small conventional basin-type solar still with an opaque cover that was positioned in the shade. The performance of an inverted trickle solar still was researched by Badran et al. [5]. The effectiveness of stepped solar stills with thermal energy storage for latent heat was investigated by Radhwan et al. [6]. A weir-type inclined solar still's theoretical and experimental performance was investigated by Sadineni et al. [7]. In a study by Mahdi et al. [8], charcoal cloth was utilised as the absorber/evaporator material in a wick-type solar still. In a multiple-wick solar still with blackened jute cloth serving as the liquid surface, Sodha et al. [9] investigated how well the still performed. The effects of a floating cum inclined wick type solar still with the influence of water flowing over a glass cover were explored by Janarthan et al. [10]. The experimental performance of a new type of slanted solar still with rectangular ridges and grooves in the absorber plate was investigated by Anburaj et al. [11]. Tanaka et al. [12] investigated how a flat plate reflector may be used to improve the slanted wick solar still.

Wicks are made of materials with a good capillary action water absorption tendency. Additionally, the wick helps absorbed water evaporate more quickly than it would in a still with a basin. The use of various wick materials for quick evaporation has been the subject of numerous studies. Hansen et al. [13] tested the analysis of the performance of several wick materials. To increase the efficiency of the solar still, the major goal of this work is to identify a good material with a good evaporative tendency to be used as wick material in inclined solar still.

The good quality wick material when used in IWSS will enhance the distillate output. The objective of the present work to experiment with different commonly used wick materials viz. Cotton cloth, Jute cloth, wool, Polyester and Terri cloth as wick for IWSS. To determine the distillate output produced experimentally by using different wicks in the climate of Raipur, Chhattisgarh, India (). To experimentally determine the characteristics such as porosity and capillary rise of different wick materials. To determine the cost effectiveness a technoeconomic analysis has been performed for different wicks.

2. Characteristics of wick materials

Porosity, water absorbency, water repellence, capillary rise, and heat transfer coefficient are major and crucial characteristics of an efficient wick material, according to the literature review. These characteristics are among all the wicking characteristics of the material.

2.1 Porosity (ϕ)

Porosity is a measure of the void (i.e., "empty") spaces in a material and is expressed as a percentage between 0 and 100% of the volume of voids over the total volume.

$$\phi = \frac{V_p}{V_b} \tag{1}$$

V_p is the volume of pore surface and V_b is the bulk volume

$$V_p = \frac{W_{wr}}{\rho_{wr}} \tag{2}$$

W_{wr} = Weight of water in pore space (kg)

ρ_{wr} =Density of water (kg/m^3)

$$W_{wr} = W_{sat} - W_{dry} \tag{3}$$

W_{sat} = Saturated weight of sample (kg), W_{dry} = Dry weight of sample (kg)

The bulk volume V_b will be given by,

$$V_b = lbt \tag{4}$$

In Eq.4 lbt is the length, breadth and thickness of sample

2.2 Heat transfer coefficient

The amount of water that evaporates inside the still depends on the evaporative heat transfer coefficient, which is a function of the heat transfer coefficient between the glass cover and the wet wick absorber surface. The difference in partial pressure of water vapor between the wick absorber and the glass cover, as well as the temperature differential between the absorber and the glass cover, heat transfer coefficient will be given by,

$$h = q / \Delta T \text{ (W/m}^{2\text{o}}\text{C)} \quad (5)$$

$$\Delta T = T_w - T_g \quad (6)$$

2.3. Absorbency of water

The rate at which water is absorbed by and transformed into another object or phase is known as its water absorbency. Water can be absorbed into an object, such as a sponge, or it can be absorbed into the atmosphere and convert into another state, such as gas.

2.5 Capillary rise

The term "capillary rise" refers to the increase in a liquid above the level of zero pressure caused by a net upward force generated by the attraction of the water molecules to a solid surface, such as glass, fabric, and soil.

3. Determination of porosity and capillary rise of wick materials

The weave of the fabric affects porosity. Water fills the porous area and remains inside the fabric. The porosity of various wick materials has been determined in laboratory by Eqs. 1-4, by weighing in dry conditions and in saturated conditions. The porosity of different wick materials has been determined and shown in Fig.1. It is seen that the porosity of cotton wick is maximum about 27.9% and the porosity of Jute wick is minimum 18.6%. The porosity of wool wick, polyester wick and Terri cloth wick is 26.2%, 21.2% and 24.3%, respectively.

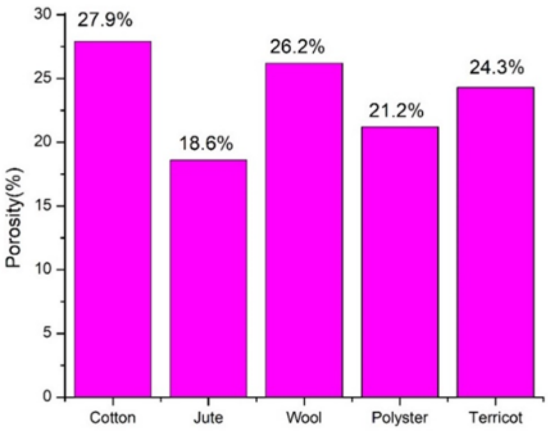

Figure 1 Porosity of different wick materials

Capillarity refers to the driving force to propel liquid through small gaps in the absence of external forces, and hence enhanced capillary force has been pursued for various applications. The different wick materials for capillary rise were oven dried before being pegged on a string and clamped on two ring stands as indicated in Fig. 2. Each material's bottom end was put into a water-filled beaker. Using a meter rule, the amount of water that rose over the course of one hour has been measured. At the point when there was no more water increase, the maximum capillary height was measured.

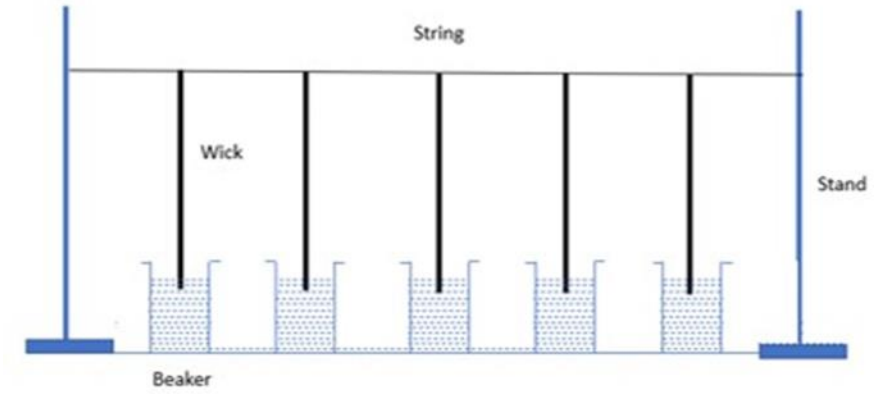

Figure 2 Experiment to determine capillary rise

The capillary rise of water from different wicks has been experimentally determined in laboratory and shown in Fig.3. The rise is maximum 120mm/h for cotton cloth and minimum 11mm/h for Polyester cloth. The capillary rise for jute, wool and Terri cot is 25mm/h, 110mm/h and 23mm/h, respectively.

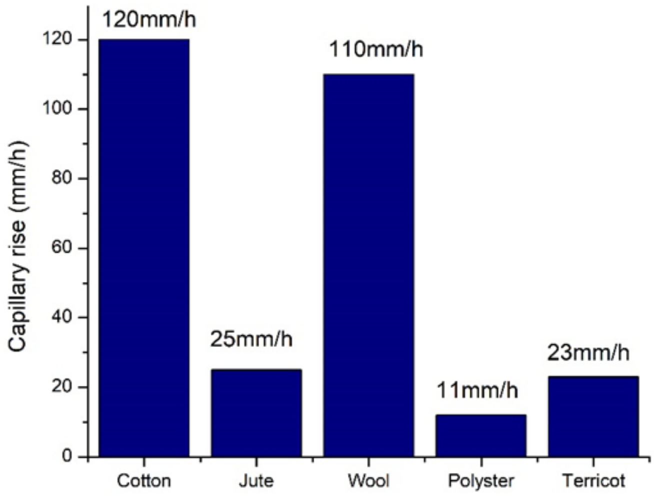

Figure 3 Capillary rise from various wick materials

4. Determination of daily distillate output using different wick materials in IWSS

Series of experiments have been performed to determine the daily distillate output from IWSS by changing wick materials. The experiments were performed on five clear days (12/03/2023, 13/03/2023/ 14/03/2023, 16/3/2023 and 19/3/2023 in the climate of Raipur, Chhattisgarh, India (). IWSS is made from MS plate (2mm) having rectangular section of area 1m^2 and height 7cm. The MS body is enclosed inside a wooden box and insulated from outside by Styrofoam insulation. Wick cloth is hanged from vertical section from inside such that it covers entire bottom portion. To allow water flow through wick a water distribution system made of PVC has been provided at the inlet of wick. To collect distillate output a gutter is provided inside. The photograph of the experimental setup is shown in Fig. 4.

Figure 4 The IWSS with cotton wick inside

Table 1. Details of various instruments used during experiment

Instrument	**Range**	**Accuracy**	**Uncertainty**
Temperature sensor K type-constantan	0°C to 150°C	±0.2°C	2% to 0.4% (10°C to 50°C)
RTD-Platinum temperature sensor	-50°C to 199.9°C	±0.1°C	1% to 0.2% (10°C to 50°C)
Digital anemometer	0.0m/s to 45.0m/s	±0.1m/s	5% (2m/s)
Pyranometer (Kipps and Zenon)	0W/m^2 to 1500W/m^2	73µV/W/m^2 (Sensitivity)	10%
Measuring flask	500mL	1mL	-

Experiment was performed in five different days by changing the wick material of IWSS. The solar radiation and ambient temperature during experiment for five days are shown in Figs. 5 and 6. The range make and accuracy of different instruments used during experiment are shown in Table 1. Solar still was kept at an inclination angle of about 21° (latitude of Raipur). The hourly distillate output from solar still was collected and measured in measuring flask. The hourly distillate output produced by still for different days with cotton, jute, wool, polyester and terri wick material is measured and shown in Fig. 7. Performance of IWSS with cotton

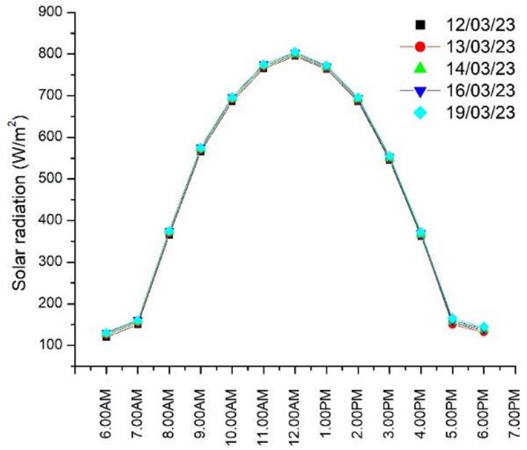

Figure 5 Hourly ambient temperature during experiment days

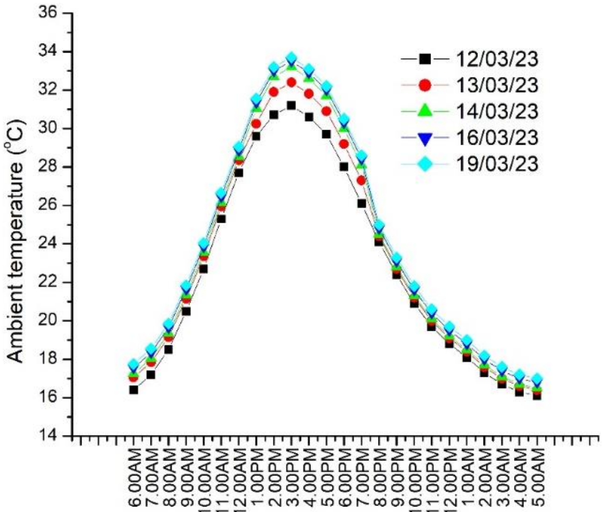

Figure. 6 Hourly solar radiation during experiment days

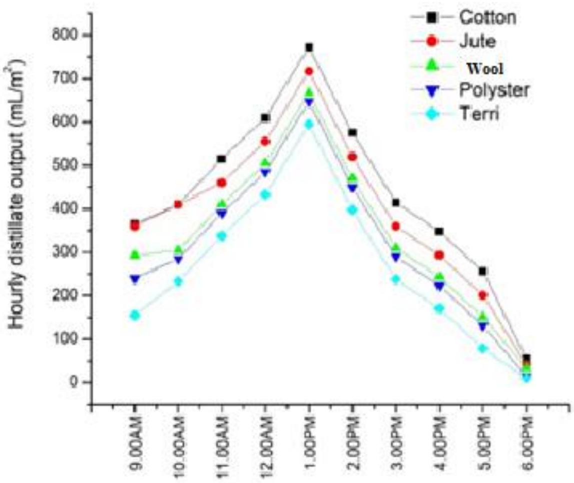

Figure 7 Hourly distillate output produced by different wicks

wick material is better in comparison to other wicks. The maximum hourly distillate output produced by cotton wick is 757mL/m^2(1.00PM) the same has been reflected by Fig.1 and Fig.2 where the porosity and the capillary rise for cotton wick was coming maximum 27.9% and 120mm/h. With jute wick material the maximum hourly distillate output produced was 705mL/m^2 the porosity for jute was 18.6% whereas the capillary rise 25mm/h. The least hourly distillate output of 545 mL/m^2 was seen with Terri cloth wick for wool and polyester cloth wick the maximum hourly distillate output produced was 655mL/m2 and 650mL/m^2, respectively. The daily distillate output produced by IWSS with different wick is determined and shown in Fig. 8.

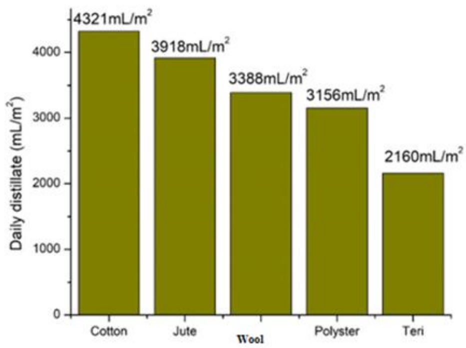

Figure 8 Daily distillate output produced by different wick materials

It is seen that the daily output and efficiency (4321mL/m^2, 46.2%) is maximum for cotton wick material and minimum (2160mL/m^2, 30%) for terri wick material. The daily output and efficiency of jute, wool and polyester wick are 3918 mL/m^2, 3388 mL/m^2, 3156 mL/m^2 and 41.9 %, 36% and 33.3 %, respectively.

5. Efficiency of different wick materials

The daily efficiency of IWSS will depend on the total daily distillate output produced, the latent heat of evaporation and the total daily incident radiation on solar still. The efficiency will be given by,

$$\eta = \frac{\dot{m}_{ew} L}{\sum It} \tag{7}$$

In Eq.7 $\dot{m}_{ew}$ is the total daily distillate output produced by solar still. L is the latent heat of vaporization I and t are the total solar radiation and time in seconds. The efficiency of the SS with different wick materials have been computed for different days by using above equation (7). It is seen that the efficiency of SS is maximum 46.2% for cotton wick material due to its more daily distillate output and minimum 30% for terii wick material. The daily efficiency of SS with jute, wool and polyester wick materials are 41.9%, 36% and 33.3% respectively.

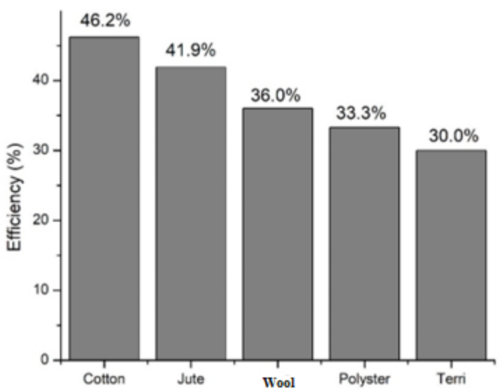

Figure 9 Daily efficiency of different wick materials

6. Results and conclusions

Wick still has some additional advantages over simple basin type SS or commonly known as SSSS. The performance of wick still depends on the quality of wick material, the material having good water absorption capacity gives more output in comparison to material showing poor porosity of water. In present work authors experimentally determined some of the characteristics like porosity and capillary rise of different wick materials (cotton, jute, wool, polyester and terri cloth). It is seen that porosity (27.9%) is maximum for cotton wick and minimum (18.6%) for jute wick. The capillary rise of water is maximum for cotton wicks, the capillary rise of water is 120mm/h. In the environment of Raipur, Chattisgarh, India, the daily distillate yield for solar stills using various wick materials has been experimentally determined. For cotton wick material, the daily distillate output is maximum 4.321L/m^2 and minimum 3.156L/m^2 for polyester wick material. Cotton wick is proved to be a stable and cost-effective material for solar stills.

References

1. Tiwari GN, Tiwari AK. Solar distillation practice for water desalination systems. New Delhi, India: Anamaya Publishers; 2007.
2. Aybar S, Egelioglu F, Atikol U. An experimental study on an inclined solar water distillation system. Desalination. 2005;180:285-289.
3. Yeh HM, Chen LC. Effects of climatic, design and operational parameters on the performance of wick-type solar distillers. Energy Convers Manag. 1986;26:175-180.
4. Minasian AN, Al-Karaghouli AA. An improved solar still: the wick-basin type. Energy Convers Manag. 1994;36:213-217.
5. Badran A, Assaf L, Kayed S, Ghaith A, Hammash I. Simulation and experimental study for an inverted trickle solar still. Desalination. 2004;164:77-85.
6. Radhwan M. Transient performance of a stepped solar still with built-in latent heat thermal energy storage. Desalination. 2004;171:61-76.
7. Sadineni SB, Hurt R, Halford CK, Boehm RF. Theory and experimental investigation of a weir-type inclined solar still. Energy. 2008;33:71-80.
8. Mahdi JT, Smith BE, Sharif AO. An Experimental Wick-type Solar Still System: Design and Construction. Desalination. 2011;267(2-3):233-238.
9. Sodha MS, Kumar A, Tiwari A, Tyagi G. Progresses in simple multiple wick solar still: analysis and performance. Sol Energy. 1986;26:127-131.
10. Janarthanan B, Chandrasekaran J, Kumar S. Evaporative Heat Loss and Heat Transfer for Open- and Closed-cycle Systems of a Floating Tilted Wick Solar Still. Desalination. 2005;180:291-305.
11. Anburaj P, Hansen RS, Murugavel KK. Performance of an Inclined Solar Still with Rectangular Grooves and Ridges. Appl Solar Energy. 2013;49(1):22-26.
12. Tanaka H. Tilted Wick Solar Still with External Flat Plate Reflector: Optimum Inclination of Still and Reflector. Desalination. 2009;249:411-415.
13. Hansen RS, Narayanan CS, Murugavel KK. Performance Analysis on Inclined Solar Still with Different New Wick Materials and Wire Mesh. Desalination. 2015;358:1-8.