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Impact Of Pre-Heated Feed Water Via Nozzle On The Performance Of A Solar Still

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Abstract
Introduction: Water is a vital resource for human health, and its purification is essential for safe consumption. Solar stills offer an eco-friendly solution for desalinating brackish and saline water using renewable solar energy. The efficiency of a solar still depends on various factors, including meteorological conditions, geometric configurations, and operational parameters.
Methods: In this study, a double slope solar still (DSSS) was evaluated under different configurations: with and without an external energy unit (EEU) incorporating nozzles for feed water pre-heating. Specifically, the setups included a 1 mm nozzle in parallel mode and a 2 mm nozzle in series mode. A water depth of 4mm is maintained throughout the experiment for the absorber basin tray by using a solenoid valve controlled by a level control circuit. The metrological parameters including solar radiation intensity, wind velocity were continuously monitored recorded at 30 minutes interval. By using a measuring jar the distillate output was recorded once in a hour besides overnight production.
Results: Among the tested configurations, the DSSS with EEU using a 1 mm nozzle in parallel mode demonstrated the highest performance in terms of water yield.A water depth of 4mm is maintained throughout the study. From the observations, it is inferred that DSSS with EEU (1mm nozzle-parallel mode) yield higher distillate production of 3700ml with a maximum efficiency of 34.96% when compared to the other three parameters chose for the study.
Conclusions: The input energy required per litre of distillate production is estimated to be 1515W/m2 for DSSS with EEU (1mm nozzle-parallel mode) and also overall daily thermal efficiency is estimated to be 43.24% .Hence, the performance and distillate production of DSSS with EEU (1mm nozzle-parallel mode) is better when compared to the other parameters such as DSSS with EEU (2mm nozzle-parallel mode and series mode) and DSSS without EEU.
Keywords: Water purification, Solar still, DSSS, EEU, Nozzle configuration.

1. Introduction

Energy scarcity and the increasing demand for clean water are two of the most critical challenges faced by developing countries like India. Rapid population growth, industrialization, urbanization, and climate change have placed immense pressure on conventional energy resources and freshwater availability. India, being largely dependent on fossil fuels for its energy requirements, faces issues such as resource depletion, environmental pollution, and greenhouse gas emissions.

In this context, the utilization of renewable energy sources such as wind energy, solar energy, geothermal energy, ocean energy, biomass energy, and fuel cell technology offers a sustainable and environmentally friendly solution to overcome the growing energy shortage in the country. Among these renewable sources, solar energy stands out as one of the most promising options due to India's geographical location, which receives abundant sunlight throughout the year. Solar energy is clean, inexhaustible, and widely available, making it highly suitable for decentralized applications in rural and remote areas. One such important application of solar energy is water purification, which is essential for ensuring safe drinking water and improving public health. Access to potable water remains a significant concern in many parts of India, especially in arid, semi-arid, and coastal regions where groundwater is often brackish or saline. Various methods are available for purifying water for drinking purposes, including distillation, filtration, chemical treatment, and irradiative treatment (Ali Samee et al., 2007).

However, many of these methods require external energy inputs, chemical additives, or sophisticated infrastructure, which may not be economically viable or environmentally sustainable for rural communities. In this regard, solar distillation using solar stills emerges as a simple, cost-effective, and eco-friendly technique for producing clean drinking water. A solar still operates on the natural processes of evaporation and condensation, similar to the hydrological cycle. The incident solar radiation passes through a transparent cover, such as glass or plastic, and is absorbed by a blackened surface in contact with the water to be distilled. This absorbed energy raises the temperature of the water, causing it to evaporate and form water vapour. The generated vapour rises and condenses on the inner surface of the transparent cover, which remains at a comparatively lower temperature due to contact with ambient air. The condensed water droplets then flow downward along the inclined cover into a collection gutter and are finally stored in a separate tank as distilled water. Impurities such as salts, microorganisms, and suspended solids are left behind in the basin, thereby producing high-quality potable water. Structurally, a solar still is an airtight basin generally constructed using materials such as concrete, cement, galvanized iron (GI) sheets, or fibre-reinforced plastic (FRP), with a transparent top cover made of glass or plastic. The inner base of the still, known as the base liner, is coated with black paint to enhance the absorption of solar radiation. Brackish or saline water is fed into the basin, where purification takes place using only solar energy (Medugu and Ndatuwong, 2009).

Thus, solar still technology represents a sustainable solution that simultaneously addresses the challenges of renewable energy utilization and safe drinking water production, particularly in water-scarce and energy-deficient regions of India.

2. **Objectives**

The primary objective of this study is to explore the effective utilization of solar energy for the purification of drinking water through solar still technology.

The work aims to design, develop, and analyze the performance of a simple and cost-effective solar still capable of converting brackish or saline water into potable water using renewable energy.

Another important objective is to evaluate the feasibility of solar distillation as a sustainable solution for addressing water scarcity in rural and remote regions with limited access to electricity.

The study also seeks to assess the efficiency of the solar still in terms of distillate yield and water quality, while identifying key parameters that influence its performance. Ultimately, the objective is to promote environmentally friendly water purification methods that reduce dependence on conventional energy sources and contribute to sustainable development.

3. Methods

The three major internal heat transfers from basin water surface to the inner glass cover by radiation, convection and evaporation shall be computed from the following empirical relationships (Rahbar and Esfahani, 2012).

Convective heat transfer from basin water to inner surface of the glass cover (q_{cw})

$$q_{cw} = h_{cw}(T_w - T_{gi}), \text{ in w/m}^2$$

Where, 'h_{cw}' is the convective heat transfer coefficient from water to inner surface of the glass cover, in w/m^2.k

$$h_{cw} = 0.884\left[(T_w - T_{gi}) + \frac{(P_w - P_{gi})(T_w + 273)}{(268.9\times10^3 - P_w)}\right]^{(1/3)}$$

P_w – Saturated partial vapour pressure at surface water temperature, in N/m^2

$$P_w = \exp\left[25.317 - \left[\frac{5144}{273 + T_w}\right]\right]$$

P_{gi} - Saturated partial vapour pressure at inner surface temperature of glass cover, in N/m^2

$$P_{gi} = \exp\left[25.317 - \left[\frac{5144}{273 + T_{gi}}\right]\right]$$

T_w -Temperature of surface water, in °C

T_{gi}-Temperature of the inner surface of glass cover, in °C

Evaporative heat transfer from basin water to inner surface of the glass cover (q_{ew})

$$q_{ew} = h_{ew}(T_w - T_{gi}), \text{ in W/m}^2$$

Where, 'h_{ew}' is evaporative heat transfer coefficient from water to inner surface of the glass cover, in W/m^2

$$h_{ew} = 0.016273 \times h_{cw} \times [\frac{P_w - P_{gi}}{T_w + T_{gi}}]$$

Radiative heat transfer from basin water to inner surface of the glass cover (q_{rw}): In calculation radiative heat transfer, basin water surface and glass cover are considered as infinite parallel planes. The radiative heat transfer (q_{rw}) from the basin water surface to the inner surface of glass cover can be expressed as:

$$q_{rw} = h_{rw} . (T_w - T_{gi}), \text{ in } W/m^2$$

Where, 'h_{rw}' is radiative heat transfer coefficient from basin water to inner surface of the glass cover, in $W/m^2.K$

$$h_{rw} = \varepsilon_{effi} .\sigma[(T_w + 273)^2 + (T_{gi} + 273)^2] . [T_w + T_{gi} + 546]$$

ε_{effi}-Effective emittance between glass cover and water mass

$$\frac{1}{\varepsilon_{effi}} = \frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1$$

σ-Stefan boltzman constant (5.67×10^{-8} W/m^2 k^4)

ε_{w}&ε_g - Emissivity of water (0.95) & Emissivity of glass (0.94)

Total internal heat transfer from basin water to inner surface of the glass cover (q_{tw}): The total internal heat transfer is the combination of convective, evaporative and radiative heat transfers from water surface to inner surface of condensing cover.

$$q_{tw} = q_{cw} + q_{ew} + q_{rw} \qquad \text{(or)}$$

$$q_{tw} = h_{tw} .(T_w - T_{gi}), \text{ in } W/m^2$$

Where, 'h_{tw}' is the total internal heat transfer coefficient from the basin water to inner surface of the glass cover, in $W/m^2.K$

$$h_{tw} = h_{cw} + h_{ew} + h_w$$

Energy fractions: The internal heat transfer by each mode is expressed as a fraction of the total heat transfer to understand the relative significance of the magnitudes of each mode of heat transfer. Thus, evaporative, convective and radiative energy fractions can be calculate using:

$$\text{Evaporative energy fraction, } F_e = \frac{q_{ew}}{q_{tw}}$$

$$\text{Radiative energy fraction, } F_r = \frac{q_{rw}}{q_{tw}}$$

$$\text{Convective energy fractive, } F_c = \frac{q_{cw}}{q_{tw}}$$

Experimental Setup: The water collection channel is designed for collecting the condensed water i.e. distillate output from glass cover plate. Two collection channels are used for water collection .The dimensions of water collection channel as follows, Length = 1612.9 mm, Breadth = 25.4 mm, Height = 25.4 mm

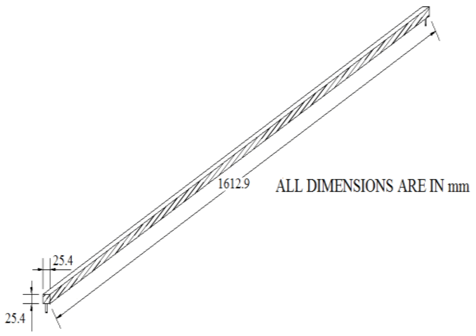

Fig. 1– Collection channel

Evaporation Enhancing unit (EEU): Evaporation Enhancing Unit (EEU) is a pre-heating unit which allows pre-heated water into the system. Along with the permission of the inventor who has applied patent for EEU (vide Indian Patent Application No. 201841028685) and also his research facilities for our experimental studies.

Layout and specifications of double sloped solar still

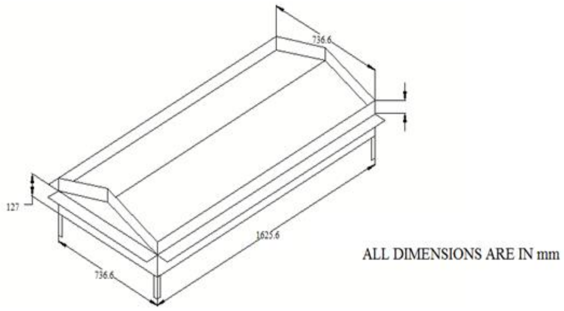

Fig. 2 - Double sloped solar still

Table No. 1 Specifications of solar still

Sl. No.	Components	Specifications
1.	Basin Area	$0.9687\ m^2 \approx 1\ m^2$
2.	Cover Plate Area	$1.28\ m^2$
3.	Transmissivity of Cover Plate	80%
4.	Thickness of Insulation	0.05 m ≈ 2 inches

5.	Thermal conductivity of Insulation	0.02 W/m.k

Fabrication: The manufacturing processes involved in fabrication of the double sloped solar still are as follows:

Table No. 2 Fabrication techniques used

S. No.	**Components**	**Manufacturing Processes**
1.	GFRP basin tray	Molding & Spray Painting
2.	Protection cover tray	Sheet metal work & gas welding
3.	Support Structure	Arc welding
4.	Cover plate	Sizing of glass, arc welding & sealing
5.	Collection channel	Sheet metal work & gas welding

The fabricated double slope solar still. The experiments were conducted during the month of February 2020 at the open terrace of Krishnasamy College of engineering and technology, cuddalore (latitude 11º75’) Tamilnadu, India. The glass cover plate slopes of the experimental setup were maintained in north-south and south-north orientation throughout the experimental work. A water depth of 4mm is maintained throughout the experiment for the absorber basin tray by using a solenoid valve controlled by a level control circuit. The metrological parameters including solar radiation intensity, wind velocity were continuously monitored recorded at 30 minutes interval. By using a measuring jar the distillate output was recorded once in a hour besides overnight production. The observations were recorded between 9.00a.m to 5.00p.m.

4. Results

Replenishment mean by how many quantity amount of raw water collect same level of raw water in the basin to maintain the static depth of water by one hours once. By using repleni-shment method, To study the four different parameters (Tables 3-9) namely;

- DSSS with EEU (1mm nozzle-parallel mode).
- DSSS with EEU (2mm nozzle-parallel mode)
- DSSS with EEU (2mm nozzle-series mode
- DSSS without EEU.

Table No.3. Observations of DSSS with EEU (1mm nozzle-parallel mode)

Time (hrs)	Metrological parameters			Process operating temperatures (◦C)			Hourly distillate collection m_{dc} (kg/m^2)
	I(t) (w/m^2)	V (m/s)	Ta (◦C)	T_w (◦C)	T_{gi} (◦C)	T_{go} (◦C)	
9	425	0.3	31.5	46.8	38.9	39.5	0.00
10	645	0.7	32.6	60.8	54.2	49.0	0.16
11	780	2.4	33.3	65.5	58.3	52.7	0.27
12	854	1.7	35.2	73.3	67.5	60.6	0.54
13	905	2.4	34.1	75.0	69.2	60.0	0.60
14	735	2.4	34.0	69.0	63.4	53.4	0.71
15	593	1.7	33.7	63.1	57.8	49.7	0.50
16	382	1.7	32.7	55.1	50.4	44.1	0.41
17	180	2.0	31.0	48.4	45.5	37.4	0.24
Overnight distillate collection (17.00 hrs to 9.00 hrs)							0.27

Net Collection of distillate: 3700(kg/m^2)

Table No.4. Observations of DSSS with EEU (2mm nozzle-parallel mode)

Time (hrs)	Metrological parameters			Process operating temperatures (◦C)			Hourly distillate collection m_{dc} (kg/m^2)
	I(t) (w/m^2)	V (m/s)	Ta (◦C)	T_w (◦C)	T_{gi} (◦C)	T_{go} (◦C)	
9	530	1.4	33.5	46.4	36.9	40.2	0.00
10	790	0.7	33.7	61.2	53.9	48.2	0.19
11	950	3.7	33.9	68.4	61.9	52.1	0.43
12	1043	1.7	34.4	69.9	62.7	55.5	0.58
13	970	3.4	34.3	70.0	63.5	53.9	0.66
14	855	3.4	34.0	68.4	62.4	52.4	0.65
15	665	2.0	33.4	66.1	61.5	51.0	0.60
16	470	3.4	32.9	58.0	53.5	45.1	0.50
17	223	1.7	32.3	48.0	44.9	39.0	0.31
Overnight distillate collection (17.00 hrs to 9.00 hrs)							0.37

Net Collection of distillate: 4310(kg/m^2)

Table No. 5. Observations of DSSS with EEU (2mm nozzle-series mode)

Time (hrs)	Metrological parameters			Process operating temperatures (°C)			Hourly distillate collection m_{dc} (kg/m^2)
	I(t) (w/m^2)	V (m/s)	Ta (°C)	T_w (°C)	T_{gi} (°C)	T_{go} (°C)	
9	508	4.4	31.3	44.2	36.5	35.8	0.000
10	720	3.1	32.5	54.5	47.1	44.5	0.155
11	862	2.4	32.9	63.6	56.6	45.9	0.380
12	893	3.7	33.1	67.9	61.7	50.0	0.470
13	878	4.1	33.4	68.2	62	51.5	0.635
14	805	4.1	32.9	65.2	59.4	48.3	0.650
15	630	5.4	32.5	60.1	54.5	45.0	0.510
16	450	2.4	32.0	55.2	50.8	42.5	0.400
17	215	4.1	31.0	46.6	44.1	36.3	0.270
Overnight distillate collection (17.00 hrs to 9.00 hrs)							0.330

Net Collection of distillate: 3800(kg/m^2)

Table No. 6. Observations of DSSS without EEU

Time (hrs)	Metrological parameters			Process operating temperatures (°C)			Hourly distillate collection m_{dc} (kg/m^2)
	I(t) (w/m^2)	V (m/s)	Ta (°C)	T_w (°C)	T_{gi} (°C)	T_{go} (°C)	
9.00	530.0	0.3	31.1	45.8	40.1	39.6	0.000
10.00	788.0	0.7	32.0	52.7	45.7	46.1	0.210
11.00	962.0	1.4	33.4	66.1	60.1	51.4	0.315
12.00	1007.0	1.0	34.2	69.7	63.8	56.8	0.555
13.00	992.0	2.0	34.7	69.0	62.6	50.9	0.630
14.00	820.0	1.7	33.5	65.7	59.7	50.9	0.545
15.00	634.0	2.7	32.2	58.5	52.8	44.2	0.530
16.00	540.0	1.4	32.1	54.6	50.1	46.1	0.320
17.00	261.0	1.0	30.9	42.6	39.3	35.9	0.255
Overnight distillate collection (17.00 hrs to 9.00 hrs)							0.290

Net Collection of distillate: 3650(kg/m^2)

DSSS with EEU (1mm Nozzle-Parallel Mode): The calculated results of DSSS with EEU (1mm nozzle-parallel mode) is represented in table as follows

Table No. 7. Results of with EEU (1mm nozzle-parallel mode)

Time (hrs)	Hcw (W/m^2.k)	qcw (W/m^2)	hew (W/m^2.k)	qew (W/m^2)	Effi (%)
9	2.030985	16.04479	14.31	113.0116	26.59
10	2.119863	13.99109	28.02	184.9009	28.67
11	2.26826	16.33147	35.83	257.9693	33.07
12	2.289846	13.2811	50.25	291.4715	34.13
13	2.331494	13.52266	54.54	316.3485	34.96
14	2.168816	12.14537	40.52	226.9336	30.88
15	2.018623	10.6987	30.05	159.2487	26.85
16	1.821415	8.560652	19.72	92.70252	24.27
17	1.488217	4.315828	12.54	36.35606	20.20
Avg:	2.059724	108.8917	31.75	1678.943	28.85

DSSS with EEU (2mm Nozzle-Parallel Mode): The calculated results of DSSS with EEU (2mm nozzle-parallel mode) is represented in table as follows

Table No. 8. Results of with EEU (2mm nozzle-parallel mode)

Time (hrs)	**Hcw $(W/m^2.k)$**	**qcw (W/m^2)**	**hew $(W/m^2.k)$**	**qew (W/m^2)**	**Effi (%)**
9	2.146387	20.9068	14.35	136.2931	25.72
10	2.194335	16.01865	29.08	212.2523	26.87
11	2.258245	14.67859	40.53	263.4367	27.73
12	2.364432	17.02391	44.40	319.6665	30.65
13	2.293662	14.9088	43.80	284.7256	29.35
14	2.203015	13.21809	39.91	239.4706	28.01
15	1.983508	9.124138	33.72	155.1312	23.33
16	1.836905	8.266072	22.55	101.4919	21.59
17	1.51693	4.702484	12.50	38.75318	17.38
Avg:	**2.088602**	**118.3314**	**31.20**	**1751.221**	**25.62**

DSSS with EEU (2mm Nozzle-Series Mode): The calculated results of DSSS with EEU (2mm nozzle-series mode) is represented in table as follows

Table No. 9. Results of with EEU (2mm nozzle-series mode)

Time (hrs)	**hcw $(W/m^2.k)$**	**qcw (W/m^2)**	**hew $(W/m^2.k)$**	**qew (W/m^2)**	**Effi (%)**
9	1.985368	15.28733	12.48	96.0644	18.91
10	2.092135	15.4818	20.89	154.6161	23.47
11	2.210957	15.4767	32.49	227.4133	26.38
12	2.214899	13.73237	39.20	243.0569	27.22
13	2.22125	13.77175	39.78	246.6296	28.09
14	2.115662	12.27084	33.92	196.7409	24.44
15	2.002165	11..21212	26.22	146.8581	23.31
16	1.784839	7.853294	19.53	85.9316	19.10
17	1.40196	3.504899	11.00	27.50363	12.79
Avg:	**2.003248**	**108.5911**	**26.17**	**1424.815**	**22.41**

DSSS without EEU: The calculated results of DSSS without EEU is represented in table as follows

Table No. 10. Results of DSSS without EEU

Time (hrs)	**hcw $(W/m^2.k)$**	**qcw (W/m^2)**	**hew $(W/m^2.k)$**	**qew (W/m^2)**	**Effi (%)**
9	1.821038	10.37992	12.86	73.28349	13.83
10	2.030315	14.2122	18.92	132.4358	16.81
11	2.155802	12.93481	35.68	214.1001	22.26
12	2.219442	13.09471	42.37	249.9835	24.82
13	2.26051	14.46726	41.61	266.2853	26.84
14	2.147892	12.88735	34.99	209.9613	25.61
15	1.987423	11.32831	24.32	138.6169	21.86
16	1.789699	8.053646	19.05	85.73647	15.88
17	1.499459	4.948214	9.65	31.84669	12.20
Avg:	**1.990175**	**102.3064**	**26.61**	**1402.25**	**20.01**

5. Discussion

The present experimental investigation evaluates the performance of a Double Slope Solar Still (DSSS) operated under a replenishment mode, in which raw water is replenished hourly to maintain a constant static water depth in the basin. This replenishment strategy ensures uniform thermal conditions, minimizes salt accumulation, and enhances continuous evaporation throughout the day. The study compares four configurations: DSSS with Evacuated Evaporation Unit (EEU) using 1 mm nozzle in parallel mode, 2 mm nozzle in parallel mode, 2 mm nozzle in series mode, and DSSS without EEU. From Tables 3–6, it is observed that the hourly distillate yield closely follows the trend of incident solar radiation. Maximum distillate collection occurs between 12:00 and 14:00 hrs for all configurations, corresponding to peak solar intensity and higher basin water temperature (Tw). The inclusion of EEU enhances heat transfer between basin water and glass cover, resulting in increased water temperature and improved evaporation rates compared to the conventional DSSS. The DSSS with EEU (2 mm nozzle-parallel mode) consistently exhibits higher basin water temperatures and inner glass temperatures than other configurations, indicating better thermal interaction and energy utilization. In contrast, DSSS without EEU shows comparatively lower temperatures, confirming the effectiveness of EEU in intensifying evaporation. The daily net distillate yields clearly demonstrate the influence of nozzle size and flow configuration. The series mode shows lower productivity than the parallel configuration due to increased pressure drop and reduced uniformity of water distribution, which limits effective evaporation. The calculated heat transfer coefficients further support the experimental observations. Higher evaporative heat transfer coefficients (hew) and evaporative heat flux (qew) are observed for DSSS with EEU configurations, especially for the 1 mm and 2 mm nozzle-parallel modes. The maximum average qew value of 1751.22 W/m² is recorded for the 2 mm nozzle-parallel mode, indicating stronger evaporation-condensation interaction. The convective heat transfer coefficient (hcw) shows moderate variation across configurations, suggesting that evaporation enhancement plays a more dominant role than convection in productivity improvement. Thermal efficiency trends reveal that DSSS with EEU (1 mm nozzle-parallel mode) attains the highest average efficiency of 28.85%, followed by 2 mm nozzle-parallel mode (25.62%), 2 mm nozzle-series mode (22.41%), and DSSS without EEU. Although the 2 mm nozzle-parallel mode yields higher distillate output, the 1 mm nozzle-parallel configuration demonstrates better efficiency due to optimized heat utilization with lower water flow rate. This indicates that while larger nozzle sizes enhance productivity, smaller nozzles improve energy efficiency by reducing heat losses. Overall, the incorporation of EEU significantly improves the performance of DSSS under replenishment mode. Parallel flow arrangements outperform series configurations due to better hydraulic and thermal distribution. Among all tested setups, DSSS with EEU (2 mm nozzle-parallel mode) is identified as the most productive configuration, while DSSS with EEU (1 mm nozzle-parallel mode) offers the best thermal efficiency. These results confirm that appropriate selection of nozzle size, flow arrangement, and replenishment strategy plays a crucial role in enhancing solar still productivity and efficiency, making the system more suitable for sustainable freshwater production in water-scarce regions.

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