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Experimental Comparative Study of Modified Double Slope Solar Stills for Enhanced Water Desalination Performance

Amit Kumar Singh[1], R.Dev[1]

[1]*Raj Kumar Goel Institute of Technology, Ghaziabad, Uttar Pradesh, India-201017*

amit4347@gmail.com

ABSTRACT

Freshwater scarcity has become one of the major global challenges due to rapid industrialization, population growth, and contamination of natural water resources. Solar distillation is an environmentally friendly and cost-effective technique for producing potable water from saline or brackish water using renewable solar energy. The present research paper investigates the performance of a Modified Basin Type Double Slope Multi-Wick Solar Still (MBDSMS) and a Modified Double Slope Solar Still (MDSSS) under the climatic conditions of Allahabad, Uttar Pradesh, India. Experimental investigations were conducted to evaluate the effect of solar radiation, brackish water depth, and wick materials on the productivity and efficiency of both systems. Transparent acrylic walls were incorporated in the modified designs to increase heat input and improve condensation collection. Experimental results revealed that MBDSMS exhibited superior productivity and thermal efficiency compared to MDSSS due to enhanced evaporation through the multi-wick arrangement. Maximum yield of 3.96 litre/m²/day was achieved for MBDSMS, whereas MDSSS produced 3.29 litre/m²/day under similar operating conditions. Reduction in brackish water depth from 2 cm to 1 cm improved productivity by approximately 7–8%, while black cotton wick material increased productivity by nearly 10% compared to jute wick. The study demonstrates that modified solar still designs with transparent walls and wick-based evaporation systems can significantly improve freshwater production using solar energy.

Keywords--- *solar distillation; solar still; multi-wick solar still; water desalination; renewable energy; thermal efficiency*

1. INTRODUCTION

Water is one of the most essential natural resources for human survival and industrial development. However, contamination of freshwater resources due to industrial discharge, agricultural runoff, and urbanization has created severe shortages of potable water across many regions of the world. Conventional water purification methods such as reverse osmosis, multi-stage flash distillation, and membrane separation require substantial electrical energy and high operational costs, making them unsuitable for remote and economically weaker regions.

Solar distillation has emerged as a sustainable alternative for producing pure drinking water from saline or brackish water using solar energy. A solar still operates on the principle of evaporation and condensation, similar to the natural hydrological cycle. Solar radiation heats the saline water, producing water vapour that condenses on a cooler transparent surface and is collected as distilled water.

Although solar stills are simple, economical, and environmentally friendly, their major limitation is low productivity. Several researchers have attempted to improve the efficiency of solar stills through modifications such as wick systems, thermal storage materials, cooling arrangements, and multi-effect designs. The present study focuses on improving solar still performance by introducing transparent acrylic walls and a multi-wick evaporation arrangement.

The main objective of this research is to experimentally compare the performance of Modified Basin Type Double Slope Multi-Wick Solar Still (MBDSMS) and Modified Double Slope Solar Still (MDSSS) under varying climatic and operational conditions.

2. LITERATURE REVIEW

Extensive research has been conducted to improve the productivity and thermal efficiency of solar stills.

Dev et al. performed comparative energy and exergy analyses of single slope, double slope, and multi-wick solar stills and concluded that multi-wick systems provide improved productivity with lower embodied energy.

El-Sebaii and El-Bialy reviewed advanced solar still designs and observed that double basin and stepped solar stills significantly improve freshwater yield. Hansen et al. investigated different wick materials and concluded that porous wick materials with high capillary rise enhance evaporation rates.

Karaghouli and Minasian proposed floating wick solar stills that provided higher productivity compared to conventional basin stills while reducing salt scale formation. Mahdi et al.

experimentally studied wick-type solar stills and observed that charcoal cloth performed effectively as an absorber and evaporator medium.

Rajaseenivasan et al. investigated double basin solar stills and concluded that productivity decreases with increasing water depth. Singh and Tiwari reported that double-effect multi-wick solar stills exhibit higher efficiency at lower flow velocities.

Previous studies clearly indicate that productivity enhancement is possible through increased evaporation area, improved heat absorption, and efficient condensation systems. However, many enhancement techniques increase system complexity and cost. Therefore, the present work proposes a simple and economical modification using transparent walls and wick arrangements.

3. EXPERIMENTAL SETUP

3.1 Experimental Location

The experiments were conducted at the Heat and Mass Transfer and Solar Energy Laboratory, Mechanical Engineering Department, RKGIT Ghaziabad, Uttar Pradesh, India. Ghaziabad experiences hot and humid climatic conditions and receives substantial solar radiation during summer months.

3.2 Construction of Solar Stills

Two solar still configurations were fabricated and tested:

1. Modified Double Slope Solar Still (MDSSS)
2. Modified Basin Type Double Slope Multi-Wick Solar Still (MBDSMS)

Both systems consisted of:

- A rectangular FRP basin of area 2 m × 1 m
- Transparent acrylic east, west, and south walls
- Blackened north wall for increased solar absorption
- Two inclined toughened glass covers fixed at 15° inclination
- Distillate collection troughs and outlet pipes
- Brackish water inlet pipe

In MBDSMS, 19 steel rods supported multiple wick layers arranged at increasing heights. The wick arrangement ensured proper capillary water flow and maintained a thin water film for rapid evaporation.

3.3 Modifications Introduced

The major modifications incorporated in the systems were:

- Transparent acrylic walls to increase solar heat input
- Additional condensate collection from south wall
- Multi-wick arrangement for thin film evaporation
- Reduced vapour travel distance for improved condensation

These modifications enhanced both evaporation and condensation processes, resulting in improved freshwater productivity.

4. WORKING PRINCIPLE

The working principle of the modified solar stills is based on solar evaporation and condensation.

Solar radiation enters through the transparent glass covers and acrylic walls and is absorbed by the blackened basin and saline water. The absorbed heat increases water temperature, causing evaporation. Water vapour rises and condenses on the inner surfaces of the glass covers and transparent walls due to lower surface temperatures.

In MBDSMS, the wick arrangement creates a thin film of water over the wick surfaces through capillary action. Since thin films require less energy for evaporation, evaporation rates increase significantly compared to conventional basin water evaporation.

The condensed water trickles down along the inclined surfaces and is collected through troughs into storage containers.

5. METHODOLOGY

Experiments were conducted from 7:00 AM to 7:00 AM (24-hour cycle) during different months including August, September, December, March, and April.

The following parameters were measured hourly:

- Solar radiation intensity
- Basin and water temperatures
- Glass cover temperatures
- Ambient temperature
- Wind speed
- Distillate yield

The effects of the following variables were investigated:

- Solar radiation variation
- Brackish water depth (1 cm and 2 cm)
- Wick material (jute and black cotton)

5.1 Efficiency Calculation

The instantaneous thermal efficiency of the solar still was calculated as:

$\eta_i = (m \times L) / (I(t) \times A_s)$

Where:

- η_i = Instantaneous efficiency
- m = Distillate yield (kg)
- L = Latent heat of vaporization
- I(t) = Solar radiation intensity
- A_s = Surface area exposed to solar radiation

Overall thermal efficiency was calculated using total daily distillate production and total solar energy input.

6. RESULTS AND DISCUSSION

6.1 Comparison between MBDSMS and MDSSS

Experimental investigations demonstrated that MBDSMS consistently outperformed MDSSS due to enhanced evaporation through the wick arrangement.

December 17, 2021

- Maximum hourly yield of MBDSMS: 743 mL
- Maximum hourly yield of MDSSS: 702 mL
- Total yield of MBDSMS: 5017 mL
- Total yield of MDSSS: 4373 mL
- Overall efficiency of MBDSMS: 32.66%
- Overall efficiency of MDSSS: 28.46%

March 17, 2022

- MBDSMS yield: 3.5 litre/m²/day
- MDSSS yield: 3.15 litre/m²/day
- Overall efficiency of MBDSMS: 23.9%
- Overall efficiency of MDSSS: 21.46%

April 18, 2022

- MBDSMS yield: 3.96 litre/m²/day
- MDSSS yield: 3.29 litre/m²/day
- Overall efficiency of MBDSMS: 27.08%
- Overall efficiency of MDSSS: 22.49%

The superior performance of MBDSMS was attributed to:

- Thin film evaporation through wick layers
- Higher evaporation area
- Reduced vapour travel distance
- Increased solar absorption by transparent walls

6.2 Effect of Brackish Water Depth

Experiments showed that lower water depth improves productivity.

MBDSMS

- Yield at 1 cm depth: 3.41 litre/m²/day
- Yield at 2 cm depth: 3.17 litre/m²/day
- Productivity improvement: 7.73%

MDSSS

- Yield at 1 cm depth: 4373 mL/day
- Yield at 2 cm depth: 4082 mL/day
- Productivity improvement: 7.12%

Lower water depth reduces thermal inertia and enables faster heating and evaporation.

6.3 Effect of Solar Radiation

The productivity of both solar stills was directly dependent on solar radiation intensity.

- Maximum productivity was observed during summer months (March and April)
- Minimum productivity occurred during winter months (December and January)

Higher solar radiation increased basin temperature, evaporation rate, and freshwater production.

6.4 Effect of Wick Material

Two wick materials were compared:

1. Jute
2. Black cotton

Results showed that black cotton wick performed better due to its superior solar absorption characteristics.

- Yield with black cotton wick: 3.86 litre/m²/day
- Yield with jute wick: 3.52 litre/m²/day
- Improvement in yield: 9.94%

Black cotton wick increased evaporation rate by absorbing more solar energy.

7. ADVANTAGES OF MODIFIED SOLAR STILL DESIGNS

The modified solar still designs provided several advantages over conventional solar stills:

- Increased heat input due to transparent walls
- Additional condensate collection from transparent walls
- Enhanced evaporation through wick arrangement
- Improved thermal efficiency
- Low operational and maintenance cost
- Environmentally friendly operation
- Suitable for remote and rural areas

8. CONCLUSION

The present experimental study successfully demonstrated the performance enhancement of modified solar still designs for water desalination.

Major conclusions are as follows:

1. MBDSMS exhibited better productivity and thermal efficiency than MDSSS under all experimental conditions.
2. Maximum productivity of 3.96 litre/m²/day was obtained for MBDSMS.
3. Reduction in brackish water depth from 2 cm to 1 cm improved freshwater yield by approximately 7–8%.
4. Productivity increased significantly with increase in solar radiation intensity.
5. Black cotton wick material enhanced productivity by nearly 10% compared to jute wick.
6. Transparent acrylic walls increased solar heat input and improved condensate collection.

The proposed modified solar still design is economical, simple, and highly suitable for freshwater production in remote and water-scarce regions.

9. FUTURE SCOPE

Future studies may focus on:

- Integration of phase change materials for thermal storage
- Use of nanofluids for enhanced heat transfer
- Hybrid photovoltaic-thermal solar still systems
- Automatic water feeding mechanisms
- Use of advanced transparent insulating materials
- Computational fluid dynamics (CFD) analysis of heat and mass transfer

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