EXPERIMENTAL STUDIES ON FINNED SOLAR STILL USING PARAFFIN WAX AS THERMAL ENERGY STORAGE MEDIUM

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ABSTRACT

An experimental study was conducted to improve the productivity of single basin single slope solar still with thermal energy storage. Two types of solar still were designed and fabricated, in order to study the performance of each still. The first one is a conventional type and the second one is a modified solar still which has squared fins and thermal energy storage material. The performance of two different solar still were tested under two cases. In the first case conventional solar still is compared with modified solar still which has square fins placed in the basin of solar still. In the second case conventional solar still is compared with modified solar still in which square fins packed with thermal energy storage material The result show that the modified still has improved the productivity by 41%,61%, than the conventional solar still under same climate conditions for the first and second case respectively.

Keywords:

Thermal energy storage, solar still, Fins, Phase change materia

1. INTRODUCTION

The availability of fresh water resources and their quality is essential for
developing countries. Simple technological innovations can improve the availability therefore contribute to a rapid enhancement of the rural areas. Fresh water resources are rivers, lakes and underground water reservoirs. About 71% of the planet is covered in water, yet of all of that 96.5% of the planet's water is found in oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps and 0.001% in the air as vapor and clouds, Only 2.5% of the Earth's water is freshwater and 98.8% of that water is in ice and groundwater. Less than 1% of all freshwater is in rivers, lakes and the atmosphere. According to the World Health Organization (WHO) 20 liters of water per capita per day are the minimum requirements to assure the basic needs.

Increasing shortage in fossil fuel supply and the growing need for fresh water have motivated further development of water desalination and purification by renewable energies. The use of solar thermal energy will cured the problem of getting fresh water. The simplest and direct applications of energy are the convergence of solar radiation into heat.

A problem in a solar energy is the availability is only during day time, during off sunset hours there was a lack, then to overcome the problem the use of thermal energy storage balance the demerit by storing the solar energy during sunshine hours and release it in sunset hours. Using latent heat storage materials which is paraffin wax can helps to store the solar energy during its availability and repack during off sunshine hours.

Solar water distillation is a simple and effective technology used to provide potable water in remote areas of developing countries. The solar stills can improve both the availability and quality of water also minimizes the evaporation losses. The collected water from solar still has been purified during the process and can be used as drinking water.
DESALINATION

A diversity of desalination technologies are being used to separate fresh water from saline water; including multi stage flash (MSF), multiple effect (ME), vapor compression (VC), reverse osmosis (RO), ion exchange, electro dialysis, phase change and solvent extraction. These technologies are expensive, however, for the production of small amount of fresh water.

6.1 SOLAR DISTILLATION

Solar distillation systems (Solar Stills) are classified broadly into two categories: passive and active solar still. Passive system in which solar energy collected by structure elements (basin liner) itself for evaporation of saline water. In the case of active solar still, an additional thermal energy by external mode is required for faster evaporation.

To accomplish this goal by utilizing and converting the incoming radioactive power of the sun's rays to heat and distill dirty and undrinkable water, converting it into clean drinkable water.

6.1.1 BENEFITS OF DISTILLATION:-

The work has been done by distillation method owing to the following benefits:-

- It produces water of high quality.
- Maintenance is almost negligible.
- All types of water can be purified into potable water by this process
- The system will not involve any moving parts and
It does not require electricity to operate.
Wastage of water will be minimum.

6.2 SOLAR STILL

Solar still is a device that produces pure water without the use of any conventional source of energy. A large use of solar stills is in developing countries where the technology to effectively distill large quantities of water has not yet arrived. Solar distillers can be used to effectively remove many impurities ranging from salts to microorganisms and are even used to make drinking water from seawater. Sol Aqua stills have been well received by many users, both rural and urban, from around the globe. Sol Aqua solar distillers can be successfully used anywhere the sun shines.

Fig 5 Assembly View of Solar Still – 3D Dimensional View

6.2.1 NEED FOR SOLAR STILLS

Adequate quality and reliability of drinking water supply is a fundamental need of all people. Without potable or fresh water there is no human life. Industries and agriculture also need fresh water without which they cannot function or thrive. Solar stills design and fabrication is
easy and could be manufactured with the locally available materials and skill. Use of solar stills is going to play a significant role in reducing water borne diseases

6.2.2 DESCRIPTION OF SOLAR STILL

The simplest application of a thermal solar thermal energy installation is in the distillation of water. The solar distiller purifies water by first evaporating and then condensing it. Distilled water contains no salts, minerals or organic impurities. Distilled water can be used for: drinking purposes, applications in hospitals replenishing batteries, and so on. Such an installation is suited to areas where water is ample. The operation of the distiller described with reference to the radiation (A) falls through glass or plastic screen (D) on to the absorber. In this case the absorber is a tray or basin filled with brackish water (B). Just as in the flat belt collector, this absorber works best if the basin is coated black. This is especially important if water is clear. The water warms and evaporates, leaving the impurities behind. This vapour condenses on the under side of screen when it has a temperature appreciably lower than that of water and the water vapour.

Fig 6 Description of Solar Still
The solar still efficiency is considered as the most important parameter to be evaluated, to ensure the best still design. For higher water levels, the efficiency slowly increasing from morning ant it will reach maximum in the late evening. It is recommended that drinking water has 100 to 1000 mg/l of salt to maintain electrolyte levels and for taste. Some saline water may need to be added to the distilled water for acceptable drinking water.

### 6.3 TYPES OF SOLAR STILL

![Classification of Solar Still](image)

**Fig 7. Classification of Solar Still**

### 6.4 DESIGN ASPECTS OF SOLAR STILL

The performance of the solar still is governed by different factors such as solar insulation, heat transfer characteristics as well as the environmental aspects. The usefulness of the solar still depends upon the economic returns obtained from the solar still. The section
summarizes the different relations used for performance evaluation and economic analysis of solar stills.

### 6.5 ASSUMPTION IN SOLAR STILL

The performance analysis is achieved by energy balance of the still. For simplifying the analysis, the following assumptions are considered:

- The level of water in the basin is maintained constant level.
- The condensation that occurs at the glass trough is a film type.
- The heat capacity of the glass cover, the absorbing material, and the insulation material are negligible.
- No vapor leakage in the still.
- No temperature gradient along the glass cover thickness and in water depth.
- The system is in a quasi-static condition.
- The heat capacity of the insulator (bottom and side of the still) is negligible.

### 6.6 MATERIAL REQUIREMENTS OF BASIN SOLAR STILL

The materials used for this type of still should have the following characteristics:

- Materials should have a long life under exposed conditions.
- They should be sturdy enough to resist wind damage.
- They should be nontoxic and instill an unpleasant taste to the water under elevated temperatures.
- They should be able to resist corrosion from saline water and distilled water.
- They should be of a size and weight that can be conveniently packaged, and carried by local transportation.
- They should be easy to handle in the field.

### 9.1 Introduction:

A solar still is a simple device for distilling water, which is powered by the radiation of the sun. Impure saline water is poured into the basin of the still where it
gets evaporated by the radiation from the sun through the transparent glass cover. The pure water vapour condenses on glass and drips down to channel, where it gets stored and it is collected in the collecting jar.

**9.2 Experimental setup:**

Solar still is a simple device which can convert available water or brackish water into potable water by using solar energy. The experimental setup consists of two single slope solar stills namely conventional and modified solar still.

![Design of solar still](image)

*Fig 16 Design of solar still*

**9.3 Materials and methods**

**9.3.1. Basin**
It is the part of the system in which the saline water for purification is stored. It is necessary that the material has high absorptivity or very less reflectivity and completely opaque. Therefore, mild steel of 22-Gauge thickness is chosen as basin material and it is fabricated for an area of 0.5m². Rectangular fins (0.02 m x 0.45 m x 0.008 m) are integrated in the basin of the modified solar still with the help of welding process. There are seven rectangular fins attached to the basin. The dimensions of the fin are chosen in such a way to avoid the shadow of the fins falling in the basin which reduces the productivity considerably. Solar radiation transmitted through transparent cover is absorbed by the black coating of the basin. Black bodies are generally good absorbers. Matte black paint is used as liner in this project.

9.3.2 Glazing

Transparent glass of 4mm thickness is selected as glazing material and the glazing is set inclined to 11° based on the geographical location of the test centre i.e., Coimbatore (11°1’N 76°58’E). The use of glass is because of its inherent property of producing greenhouse effect inside the still. Glass transmits over 90% of incident radiation in the visible range.

9.3.3 Condensate channel

The condensed water in the glazing trickles to the condensate channel. Pipe of required dimension is first cut out to one fourth of its diameter, and then it is placed inside the still in such a manner that the inclination is 3°. The inclination is kept for the quick flow of condensed water into the collecting jar.

9.3.4. Wooden casing
A wooden casing is used to enclose the basin and the transparent glass cover is mounted in the wooden casing. It also acts as a good insulation material and it ensures the whole setup is air-tight.

9.3.5. K-Type Thermocouple:

Type K (chromel-alumel) is the most common general-purpose thermocouple with a sensitivity of approximately 41 \( \mu \text{V/}^\circ\text{C} \). It is inexpensive, and a wide variety of probes are available in the range of \(-200^\circ\text{C}\) to \(+1350^\circ\text{C}\). In this work 11 Thermocouples are used. They are used to measure the basin water temperature (4 Nos), glass cover temperature (4 Nos), chamber temperature (2 Nos) and ambient temperature (1 Nos).

9.3.6. Temperature indicator:

Temperature indicators are instruments which can process signals from temperature sensors and show them on the display. A 12-point temperature indicator is used to indicate the various values of temperature from the thermocouples.

9.3.7. Solarimeter:

A solarimeter is a type of measuring device used to measure combined direct and diffuse solar radiation. An integrating solarimeter measures energy developed from solar radiation based on the absorption of heat by a black body.
A conventional still is modified still is fabricated for a proposed area of 0.5 m². Square fins of dimensions 20 mm x 20 mm x 40 mm is placed in the basin of the still. Forty eight square fins are attached to the basin.

An mild steel is used for fabricating the still basin with an area of 0.5 m². The bottom and side of basin are insulated by wood to minimize heat losses. The glass cover of thickness 5 mm is used as the condensing surface and the slope of the glass cover are fixed as 13° which is nearly equal to the latitude of the location (Coimbatore –latitude 11° N, longitude 77°55’ S). The surface of the basin is painted black for maximum absorption of solar radiation. The solar still is oriented in North-South direction to receive solar radiation throughout the working hours of the day. A collector of angle 30° is used to collect the water and delivery to the bottle.
9.5.1 Calculation of fins

It is the part of the system in which the brackish water to be distilled is kept. It is therefore essential that it must absorb solar energy. Hence it is necessary that the material have high absorptive or very less reflectivity and very less transitivity. These are the criteria for selecting the basin material. The material used for the fabrication of basin was mild steel of 22-Gauge thickness is chosen as basin material with the dimension of 1000×500mm. The area of chamber is 0.5 m². square fins (20 mm x 20 mm x 40 mm) are integrated in the basin of the modified solar still with the help of welding process. There are forty eight square fins attached to the basin. The dimensions of the fin are chosen in such a way to avoid the shadow of the fins falling in the basin which reduces the productivity considerably. Due to the presence of saline water, solar radiation transmitted through transparent cover is absorbed by the black coating of the basin. Black bodies are generally good absorbers and paints are reducing corrosion. Matte black paint is used as liner in this project.

9.5.2 Calculation of PCM stored:

Phase Change Material (PCM) which is paraffin wax is introduced into the fins and below the basin. The quantity of PCM that can be stored is calculated as follows.

Volume of PCM in ONE Fin = l * b * h
= 0.02 * 0.02 * 0.04
= 0.000016 m³

Volume of PCM in FOURTY eight Fins = 0.000016 * 48
= 0.000768 m³

Mass of the PCM = Volume * density
= 0.000768 * 9 = 0.6912 kg.

Maximum Mass of PCM that can be stored in Fins is 0.6912 kg

Volume of PCM in tray = l * b * h
= 1 * 0.5 * 0.01 (Max. height to be filled is 0.01m)
Mass of the PCM = Volume * density

= 0.005 * 900

Mass of the PCM = 4.5 kg

Mass of PCM that can be stored beneath the basin = 4.5 kg of PCM

Total PCM that can be stored (4.5 + 0.5) = 5 kg of PCM

- When PCM was stored in the fins the absorptivity of the fins got reduced and it resulted in the reduction of the total distillate output.
- Hence the PCM stored over the fins is removed to increase the effective absorber area and the solar still is tested for its performance by loading 3 kg of PCM.
- The results and analysis of the finned still integrated with TES is done when 3 kg of Paraffin wax is loaded.

**Therefore, Actual Quantity of PCM Loaded = 3 kg**

**Table 3. Accuracy and Range of various measuring Instruments**

<table>
<thead>
<tr>
<th>S. No</th>
<th>Instrument</th>
<th>Accuracy</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Thermocouple</td>
<td>±0.1 °C</td>
<td>0–100 °C</td>
</tr>
<tr>
<td>2.</td>
<td>Temperature Indicator</td>
<td>+1 °C</td>
<td>0-300 °C</td>
</tr>
<tr>
<td>3.</td>
<td>Solar meter</td>
<td>±1 W/m²</td>
<td>0–2500 W/m²</td>
</tr>
<tr>
<td>4.</td>
<td>Collecting jar</td>
<td>±10 ml</td>
<td>0–1000 ml</td>
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RESULT AND DISCUSSION
10.1 Performance of SS at different water depth

Fig 18 Variations of conventional SS productivity with time at various water depths.

Fig 18 shows the productivity of conventional solar still was compared with time at hourly basis. For conventional still for different depths of saline water. As expected, stills at lower depths give higher efficiency in all configuration. The yield of conventional still was better at 2cm water depth than other two water depths (3cm, 4cm). The lower water depth give rise to higher rate of evaporation, thereby the collected water was increased.
10.2 Comparison of convectional SS with SSWSF

A) Effect of Water Depth

The overall performance shows that the finned still is better than the conventional still at all depth conditions. A square finned still has a higher performance due to higher exposure area and more heat transfer. Thus a 2 cm depth of water is selected for further discussions. The efficiency of square finned solar still at a 2 cm depth of water is 15% and higher than conventional solar still.

B) Effect of solar radiation on modified still:

Fig19 Modified solar still water depth variation

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Fig 20 Modified solar still productivity varies with solar insolation

Fig 20 shows it can be seen that the solar intensity was maximum at the mid noon whereas, higher the intensity of solar radiation higher the distillate output due to more heat transfer on fins This time lag of the maximum ambient air temperature and maximum solar intensity is mainly due to the thermal capacity of the atmospheric air, besides, factors like air density, humidity, quality and others may also affect.

C) Effect of Cumulative Distillate Output:

![Graph showing cumulative distillate output]

Fig 21 Cumulative output of modified solar still

Fig 21 shows the distillate output was measured on hourly basis and then cumulative distillate output was calculated for both the conventional and modified solar still and the cumulative yield for the whole day was found to be increased in finned solar still than conventional solar still.

D) Effect of Temperature Difference between Basin water temperature and Glass temperature:
Fig 22 Temperature difference between glass and water

A fig 22 show productivity also varies on water–glass temperature difference. Condensation rate in glass cover is directly proportional to the difference between the water and glass temperature. The mass and a higher evaporation rate occur in square finned still which increases the thermal capacity of the still. The highest water–glass temperature differences maximize the distillate output. An important observation is that, fin-glass cover temperature difference is always positive, even in the morning hours when the basin water temperature is lower than the cover temperature. This corresponds to the fact that the fin type still starts producing in the morning hours, because the vertically extended fins start receiving the solar radiation and due to their low thermal inertia, evaporation starts rapidly. During the low insolation during off-sunshine period, the distillate production is supplemented from the relatively warm basin water, thus a reasonable nocturnal production is also obtained. For the day time (9 A.M. to 10 P.M) it was 23% higher in the month of March.

10.3 Comparison of convectional SS with SSWSF+TES

By the integration of heat transfer surfaces (fins) and thermal energy storage medium, the productivity of solar still was continuous for the whole day. The decreasing level of distillate output during off sunshine hours was boosted by thermal energy storage materials by heat release during night hours. Thus the higher yield was achieved by using both fins and thermal energy storage material (paraffin wax) by keeping the basin water at low depth.
Fig 23 Effect of fins and TES in solar still

Fig 23 shows a solar radiation is at the highest position between 12:00 and 01:00 pm. Solar still efficiency is dependent on the solar energy. Thermal energy storage materials are used to store the energy during the sunshine hours and release during off-sunshine hours to improve the distillate output. Hence, to use excess energy, thermal energy storage materials is employed, which keeps the excess thermal energy and release during off-sunshine hours for increment in distillate output and efficiency.

A) Effect of Productivity:

Fig 24 Effect of productivity
Fig 24. Shows a comparison of the overall still performance with and without PCM (paraffin wax) at the reference case of parameter values. With paraffin wax (TES), the effective heat gained is more flattened during both PCM melting and solidification periods. At peak hours, the solar insulation is increasing (800W/m$^2$), the solar still with fins and thermal energy storage medium absorbs more heat and gives more yield.

B) Effect of Cumulative distillate output:

![Diagram of Solar Intensity I(t) vs Time (in hrs)](image)

Fig 25 Effect of Cumulative distillate output

C) Effect of Temperature Difference between Basin water temperature and Glass temperature:
Fig 26 Effect of Temperature Difference between Basin water temperature and Glass temperature

Fig 26 Illustrates the hourly variation of temperature difference between basin water and glass inner surface compared with solar radiation. Since the solar still with fins has comparatively heat capacity than the conventional solar still it is able to trap maximum amount of solar insolation and hence the difference will be maximum for the still with fins.

D) Effect of Instantaneous Efficiency:
Fig 27 Effect of Instantaneous Efficiency for 2 cm Water depth

Fig 27 shows Illustrates the hourly variation of Instantaneous efficiency for 2 cm Saline water depth. The efficiency of the still with fins starts to increase from morning and the trend continues till the evening. The instantaneous efficiency is high when the solar intensity is high.

CHAPTER 11
CONCLUSION

In this work the performance evaluation of solar still with Square fins and finned solar still with Thermal Energy Storage (TES) is compared to that of the
conventional solar still. From the above experimental work, the following conclusions are drawn.

- The solar still when tested with 2 cm depth of saline water yields more distillate output than 3 cm and 4 cm depth of saline water.
- The temperature difference between the water in the basin and glass cover is high for Finned Still integrated with TES as the heat capacity of this still is more.
- The productivity of the still with TES is low during the initial hours of the day as TES material traps most of the heat. But the productivity is comparatively high after the sunshine hours.
- The distillate output of the Finned Solar still with TES is higher when the solar insolation is high.
- The still with fins enhances the daily efficiency by 41% whereas the still with fins and TES enhances the daily efficiency by 61% when compared to that of the conventional solar still.

**CHAPTER 12**

**REFERENCES**

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