Design and Fabrication of Single Slope Solar Still Using Metal Matrix Structure as Energy Storage

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Abstract

Solar still act as one of the most economical way of converting saline water into fresh water. In this article the performance of conventional solar still is compared with that of modified solar still in which metal matrix structures are used as a sensible heat storage media, thus it saves the excess energy produced during day time and utilizes the sensible heat energy from the metal matrix structure at the evening or night time. The metal matrix structure is immersed in the middle of the basin where saline water is stagnated. In the solar still, the sensible heat has been released from the metal matrix during less solar intensity hours. An attempt is made to utilize the maximum amount of the incident solar energy and to utilize the sensible heat which is accumulated in the metal matrix structures. Its yield and efficiency are compared with the conventional still under the same climatic condition. It is found that average still yield and efficiency in the modernized still with metal matrix increases–significantly with low cost for this modification as it is very cheap and easily available.

Keywords- **Solar still, yield, saline, sensible heat storage, metal matrix structures.**

I. Introduction

Solar still is a portable and sparing device for producing potable water from saline water, by making use of solar radiation, which is freely and copiously available throughout the year. The amount of the seawater and fresh water on the globe are 96.54% and 2.53%, which is very less when compared to total water, and the percentage of drinking water directly available is only 0.36% of the total water. Although, progress and development has occurred in most parts of the world, there are areas, still isolated and vestigial where even the primary requirement of electric power is either deficient or totally absent till date. This makes the solar still a necessary option for obtaining potable water in such areas, where saline water is available. The rapid wipe out of fossil fuel reserves compel us to think of the vastly copious renewable energy and its applications, whether in remote or vestigial areas. With all the attractive features and potable water option for the future, the solar still so far could not become an efficient alternative for the modern water purifying process. It is mainly due to its low efficiency and low productivity of the solar still.

Numerous attempts have been made by many researchers to increase the rate of evaporation of water and utilize the maximum solar energy which incident on the still to enhance the system efficiency by providing maximum evaporation surface within the available space of the still. Researchers have used different techniques to increase the yield of the solar stills. Researchers from all parts of the world have tested a number of designs and modifications in the solar still. Various factors such as glass cover gradient, glass cover surface area, basin insulation, basin water depth and basin material besides the climatic factors such as solar intensity, ambient temperature and many such operating factors have been investigated.

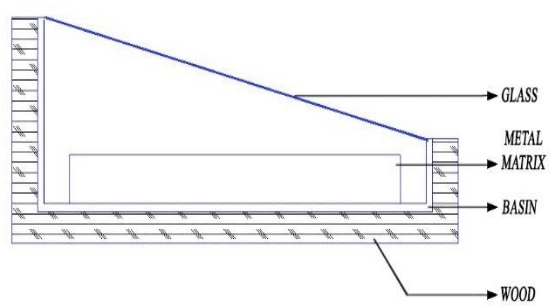
The aim of research is to develop a highly efficient solar still of simple construction, applicable to small units of production at lower costs. It is also aimed at developing a solar still with heat recovery system, to attain maximum efficiency. It is a solar distillation system suitable for arid regions where the solar still should be very simple in design, compact for usage and easy for maintenance or set right by any set of people with limited technical means. The performance of the modified solar still is tested and compared with conventional still of identical dimension and material under the same climate conditions.

II. Literature Review

Kabbara, M. J., & Abdallah, N. B.[1] investigated experimentally the performance of a thermal storage unit with phase change material and analyze the storage system in terms of its storage capacity and the heat transfer rate to the phase change material. Fan, L. W., Fang, X., Wang, X., Zeng, Y., Xiao, Y. Q., Yu, Z. T., Cen, K. F. [2] investigated experimentally by adding different carbon nanofillers for the thermal conductivity property and energy storage property of paraffin-based nanocomposite phase change materials for thermal energy storage. Tian, Y., & Zhao, C. Y. [3] reviewed on solar collectors and thermal energy storage in solar thermal applications. Gude, V. G., Nirmalakhandan, N., Deng, S., & Maganti, A. [4] presented a low temperature desalination process competent of producing higher freshwater yield was designed to utilize the solar energy obtained from flat plate solar collectors. Regin, A. F., Solanki, S. C., & Saini, J. S. [5] reviews the development of available latent heat thermal energy storage technologies and the different aspects of storage such as material, climatic condition, heat transfer, applications and new PCM technology innovation have been carried out. Kalogirou, S. A. [6] analyzed the various types of solar thermal collectors and applications. Zalba, B., Marín, J. M., Cabeza, L. F., & Mehling, H. [7] carried out a review on the history of thermal energy storage with solid-liquid phase change on three aspects materials, heat transfer and applications. Orr, B., Singh, B., Tan, L., & Akbarzadeh, A. [8] worked on making a bench type, proof of concept model of power production by thermoelectric cells using heat pipes and hot engine exhaust gases. Rahim, N. H. A. [9] proposed a new approach to store excess heat energy in horizontal solar desalination stills during daytime for the continuation of the process at night. Gude, V. G. [10] reviewed on current energy storage options for different desalination processes powered by various renewable energy and waste heat sources with focus on thermal energy storage and battery energy storage systems. Nithyanandam, K., & Pitchumani, R. [11] illustrates a methodology for design and optimization of LTES with embedded gravity assisted heat pipes (HP-TES) for a CSP plant operation. Mahian, O., Kianifar, A., Kalogirou, S. A., Pop, I., & Wongwises, S. [12] suggested to use the nanofluids in different solar thermal systems such as photovoltaic/thermal systems, solar ponds, solar thermoelectric cells, and so on. Srivastava, P. K., & Agrawal, S. K. [13] proposed a simple and economical model for the basin type solar still with porous fins which are made up of darkened old cotton rags which are partially dipped in the basin water, while the rest of the part extended above the basin water surface. Omara, Z. M., Hamed, M. H., & Kabeel, A. E. [14] conducted an experimental study to improve the productivity of basin solar stills by increasing the surface area of absorber and rate of heat transfer between saline water and absorber. Sakthivel, M., Shanmugasundaram, S., & Alwarsamy, T. [15] presents a new approach to improve the efficiency of a solar still by introducing a medium to provide large evaporation surface and utilize the latent heat of condensation and conducted experiments on a conventional single slope solar still and on a regenerative solar still with jute cloth. A.E. Kabeel, Mohamed Abdelgaied [16] modified solar still with multi-groups of two coaxial pipes in the still basin and enhanced the distillate water productivity.

III. Experimental procedure

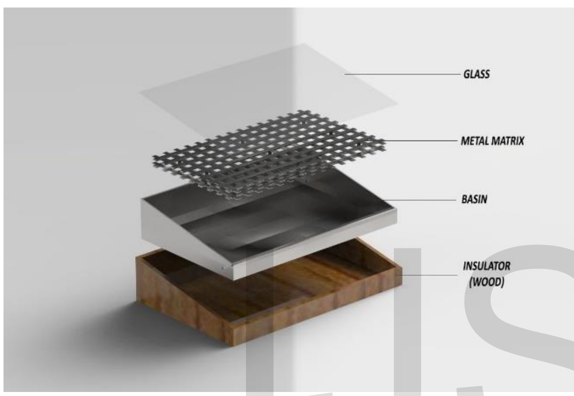
The experimental study was conducted at the south Indian city of Coimbatore (10°56'N, 76°54'E). A schematic diagram of a single slope solar still with metal matrix structures are shown in the Fig. 1.



(Fig.1: Schematic diagram of the modified still with metal matrix structures)

Initially a 3D model of the modified solar still is designed in SolidWorks. The exploded view of the modified solar still is shown in Fig. 2.

The photograph of the modified solar still is shown in Fig. 3~~.~~ A single sloped basin type solar still was constructed of mild steel sheet as shown in Fig. 1 with basin area of the still is about $1m^2$. The cover slope was given an approximated angle of 11°, which is nearly equal to the latitude angle of Coimbatore, since very low cover inclination causes the distillate droplets to fall back to the basin water, whereas large cover inclination increases the vapor length and the inside still air mass, resulting in delayed saturation of inside air and reduced output. Further, glass cover with inclination equal to the latitude angle results in receiving solar radiations normal to the glass cover for most parts of the year.



(Fig.2: Exploded view of the modified still with metal matrix structures)

(Fig.3: Pictorial view of modified solar still with metal matrix structures)

A mild steel pipe of 0.5inch was fitted through the side wall of the still for feeding saline water for the basin. Underground bore well water is used as saline water sample in the experiments. In this solar still, the metal matrix is immersed into the basin saline water. The metal matrix structures are also made of mild steel sheets, which is used for the basin. The mild steel sheets of 3mm thickness was selected for matrix structure. The horizontal and vertical length of the sheet metal matrix vary according to the basin dimensions. Hence the length of the horizontal sheets are 1m and that of the vertical sheets are of 0.750m. Both the horizontal and vertical sheets are arranged one by one alternatively and crossing each other, and hence the horizontal sheets are placed over the vertical sheets and vice versa.

While most of the incident solar energy is absorbed by the surface of the basin through the saline water, remaining portion of energy is absorbed by the metal matrix. The metal matrix structures increases the convection rate in the modified solar still. This leads to the increase in the rate of evaporation of water. The effective basin area of still is 1.250 m×0.800 m. The still cover is made of 0.005 m thick, ordinary transparent glass and kept on the wooden frame at an inclined angle of 11° with respect to the horizontal ground level.

The initial basin water depth was kept at 6 cm. A small hole was made on the rear wall of the basin for inserting thermocouple wires into the still. Out of the two stills, one was kept as a conventional single sloped basin type solar still, whereas the other still was converted into the proposed modified design. In the modified still, as shown in Fig.3 metal matrix structures are placed at the bottom of the basin so that the metal matrix structures will be completely immersed in the saline water.

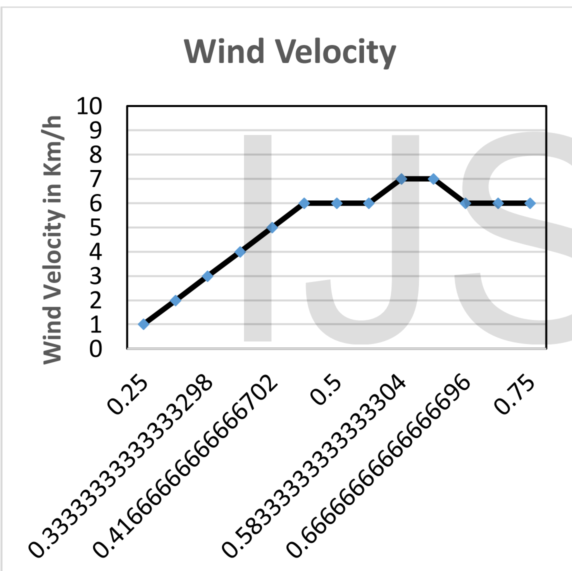
Hourly readings of the solar intensity, ambient air temperature, vapor temperature, saline water temperature, metal matrix temperature, outlet potable water temperature, basin temperature and glass temperatures of both the conventional and modified stills are recorded from 6:00 AM to 6:00 PM.

The solar intensity is measured by a digital solar power meter with the range of 0–1999 W/m^2 and with a resolution of 0.1 W/m^2 and LCD display. The temperatures were measured with the help of calibrated Type J (iron-constantan) thermocouples connected to the digital temperature indicator. To keep the whole system in vapor tight, silicon rubber is used as sealant because it remains elastic for quite a long time even at high temperature. And also the inlet water pipe is immersed in the saline water sump, so that there won't be any vapor loss through the pipe.

The tests were performed on clear days and each test was conducted for one month, out of which the best observations have been presented. The experiments were conducted from the month of February to March. During the experiments, both the conventional and modified stills were placed along the east–west direction and inclined glass cover surface faces south throughout the day to intercept maximum solar radiation throughout the day to obtain maximum efficiency on the modified solar still.

IV. Results and Discussions

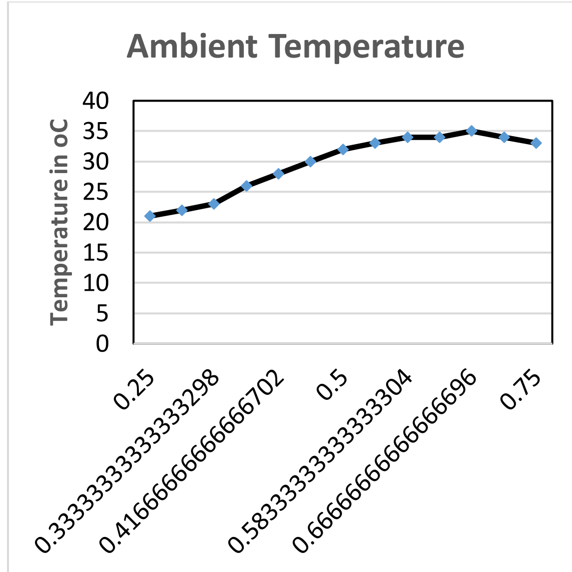
The performance of the modified still with metal matrix structures in the basin and the conventional still was installed and tested in Coimbatore, India. Through



(Fig.4: Wind velocity vs. Time)

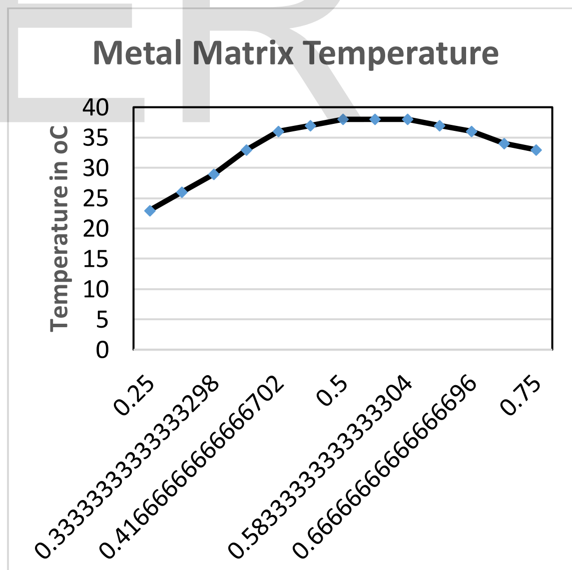
the test days the speed of the wind changes from 1 to 7 km/h. The Fig. 4 shows the wind velocity with respect to time.

The ambient temperature of the atmosphere ranges from 21ºC to 37ºC. The Fig. 5 shows the temperature range with respect to time.



(Fig.5: Ambient Temperature vs. Time)

The temperature in the metal matrix ranges from 23ºC to 40ºC. The Fig. 6 shows the temperature range of the metal matrix with respect to time.



(Fig.6: Metal matrix Temperature vs. Time)

The solar radiation intensity during day time ranges from 0-1000W/m^2. The Fig. 7 shows the solar radiation intensity with respect to time. The solar intensity is maximum at 1:00PM and is zero during the initial time of the experiment.

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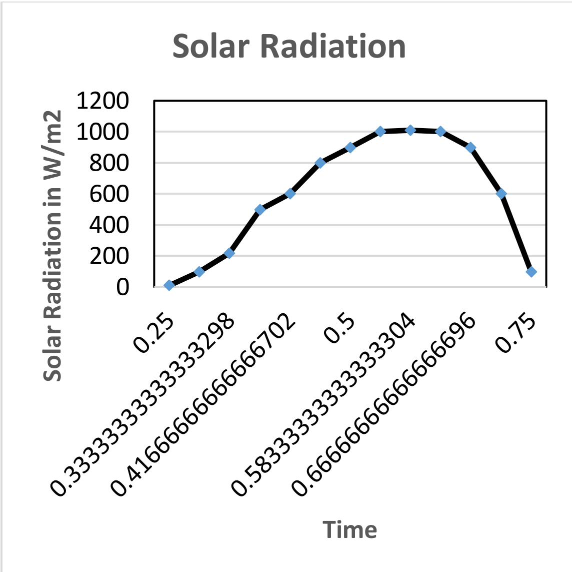
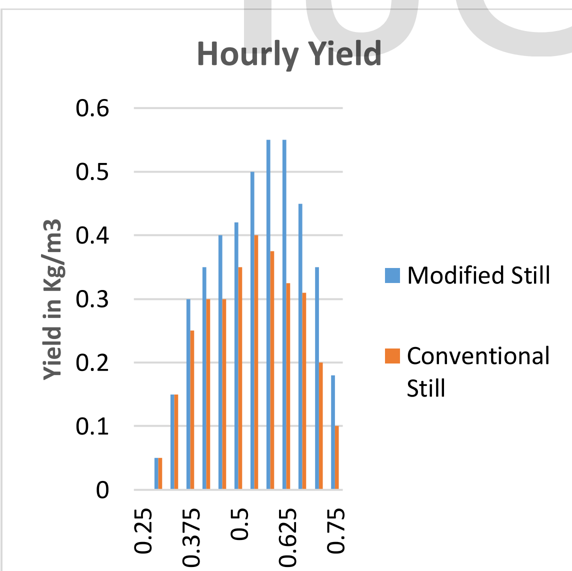


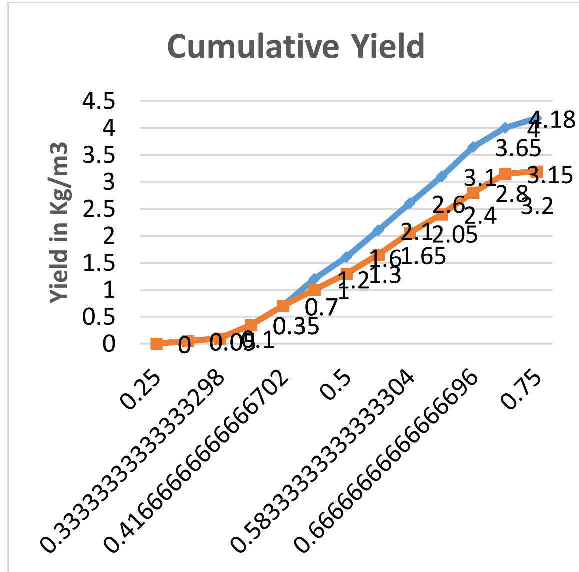
(Fig.7: Solar Radiation Intensity vs. Time)

The yield during day time ranges from 0-4l/m^2. The Fig. 8 shows the yield between the conventional solar still over the modified solar still with respect to time. It also shows that the yield of the modified still is higher than the conventional still to a great extent. This is due to the implementation of metal matrix structures in the modified solar still.



(Fig.8: Hourly yield vs. Time)

The cumulative yield between the modified and the conventional solar stills are shown in the Fig. 9. The yield of the conventional solar still is maximum at 1:00PM, but it is lesser than that of the modified solar



(Fig.9: Cumulative yield vs. Time)

still's yield at the same time. The modified solar still's yield is higher at 2:00PM. At this time the productivity of the still is higher as the solar intensity is maximum at this time.

It is surely understood that the productivity of still is emphatically reliant on the intensity of solar radiation available. The measured data of the ambient temperature is shown in Fig. 5 and solar radiation are shown in Fig. 7. Also the wind velocity is measured by the anemometer and the data of the wind velocity with respect to time is shown in Fig. 4. Through the test days the measured data of the solar radiation intensity in the range of 0–1000W/m^2 and the ambient air temperature in the range of 21–37^o C. As shown in Fig. 5 and Fig. 7. Ambient temperature and solar intensity increment to their extreme value at noontime and slowly moderate after that. Also, Fig. 6 shows the measured temperatures of the metal matrix structures for modified solar still with metal matrix structures in basin. The maximum temperature of saline water in the basin was 96^{o}C at 1:00 pm; at this point the glass cover's temperature in the ranges of 25–33^{o}C. Moreover, at the same ambient conditions for conventional still the maximum temperature of basin is about 79^{o}C, while glass covers temperature various from 24^{o}C to 32^{o}C. This temperature difference is responsible for the evaporation rate of the saline water in both conventional and modified solar still.

The hourly productivity for the modified still with metal matrix structures in the basin and the conventional still are shown in Fig. 8. As shown in figure the hourly productivity depends on the saline water temperature in the still, in the morning the hourly productivity equal to zero around 6:00AM in the morning, because the low temperature, after that the hourly productivity increase to their greatest value at noontime about 2:00PM and after noontime the hourly productivity decreases with time due to decrease the saline water temperature.

The hourly productivity for modified still with metal matrix structures in basin is higher than that of conventional solar still. This is because of the still productivity function in the temperature difference between the saline water and glass cover, the temperature difference for modified still is higher than that of conventional still and hence the evaporation rate increases in the modified still.

The solar stills daily efficiency, η_d are calculated based on the sum of hourly condensate production m_p, the latent heat h_{fg} at the average temperature of basin water T_w, average solar radiation I(t) over the whole area A:

$$\eta_d = \frac{\Sigma m_p \times h_{fg}}{\Sigma A \times I(t)} \quad (1)$$

The latent heat h_{fg} was determined from Eq. (2) El-Dessouky and Ettouney [17]:

$$h_{fg} = [\,2501.9 - 2.40706T_w + 1.192217\times10^{-3}T^2_w - 1.5863\text{x}10^{-5}T^3_w]\times10^3 \quad (2)$$

The daily productivity for both modified still with metal matrix structures in basin and conventional still are shown in Fig. 9. As shown in Fig. 9 the daily productivity for modified still is 3.40kg/m^2 a day and the conventional still 2.72kg/m^2 a day, respectively.

V. Cost Analysis

Economic analysis for both modified solar still with metal matrix structures in basin and conventional still is presented in this section. The average daily productivity along the year can be estimated 5.43 l/m^2 day, and 3.25 l/m^2 day for the modified solar still and conventional solar still, respectively. Assume the working days per year are 340 days/year, where in India the sun ascends along the year. The total cost of distilled water productivity per liter (TC/L) is estimate by using Eq. (3).

$$TC/L = \frac{AnnualTotalcost}{AnnualWaterProductivity} \quad (3)$$

Annual total cost (ATC) are estimated by using the annual fixed cost (AFC), annual salvage value (ASV) and annual running and maintenance cost (ARMC) as following by Fath et al. [18]

$$ATC = AFC + ARMC - ASV \quad (4)$$

$$AFC = FC - (RF) \quad (5)$$

Where (FC) is the fixed cost.

The recovery factor (RF) can be determined by:

$$RF = \frac{ix(1+i)^n}{(1+i)^n - 1} \quad (6)$$

In the present study take the life year (n) 10 years and the interest per year (i) 12%.

$$ARMC = 30\%AFC$$

$$ASV = S \times SFF$$

The salvage value (S) which represent about 20% of the fixed cost (FC). The sinking fund factor (SFF) can be determined by:

$$SFF = \frac{i}{(1+i)^n - 1} \quad (7)$$

By equation (7) the cost analysis for the different systems, which shows that the total cost of one liter of distilled water productivity for the modified stills and conventional still are 0.02 $ and 0.021 $ respectively.

VI. Conclusion

An experimental study was conducted to evaluate the performance of the proposed modified still with metal matrix structures. From the results obtained, the following conclusions are obtained.

- Faster early morning start-up and enhanced evaporation rates were obtained in the case of the modified still.
- Side and base heat losses are negligible in the case of the modified still.

- Reasonable amount of nocturnal output is also obtained in the modified still.
- The modified still results better performance at smaller basin water depth.
- It is a simple and economical modification for the existing basin type solar stills.
- The modification can also be effectively applied to the deep basin stills.

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