iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** V **Month of publication:** May 2021

DOI: https://doi.org/10.22214/ijraset.2021.34331

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue V May 2021- Available at www.ijraset.com

Design and Fabrication of Thermosyphon Water Purification System

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Abstract: Lack of clean drinking water in rural areas is a huge problem during the occurrences of floods and other environmental disasters. Often, it takes a long time to transport potable water to these areas resulting in health issues for the residents.
In this research, a solar power-based water purification system using PCM to produce clean drinking water in flood-affected areas or remote areas where potable water is difficult to obtain is proposed. Purification reduces the concentration of particulate matter including suspended particles, parasites, bacteria, algae, viruses, and fungi as well as reduces the concentration of a range of dissolved and particulate matter.
The purification system available is not easy to get for poor people. So we are using a different technique for water purification system is solar distillation technique, which is very cheap and convenient. These Thermosyphon purification system is a modification of conventional solar still but the efficiency achieved is much higher then the conventional solar still. There are 5 major components in our design consists of Upper basin, Lower basin, Thermosyphon system, Diffusion still, and PCM chamber.
The dirty water inlet is taken into Lower basin, upper basin, and diffusion still. Initially the temperature of water in the lower basin is low, so to increase the temperature of the water, thermosyphon loop system is connected with the lower basin. The energy from the lower basin is transferred to the condensing cover and the side walls of the tank which is been wasted to surroundings will be captured by upper basin and diffusion still. In diffusion still, there will be a successive plate, so energy from sidewalls will be evaporated and will be diffuse in a thin gap and it will get condense of the facing surface and that water will be collected in the outlet.
We will be adding phase-changing material, which helps the purification to work on in absence of sunlight. So our basic design of the project is to increase the rate of evaporation and condensation process.
Keywords: PCM-Phase Changing Material, Purification, Diffusion, Evaporation Solar energy, Thermosyphon loop.

I. INTRODUCTION

Solar energy has been identified as one of the excellent and sustainable alternate energy sources for the future. However, the effective use of solar radiation is hindered by the intermittent nature of its availability, limiting its use and effectiveness in domestic applications, notably water heating. Water heating is one of the qualities of the direct use of solar energy, and it is an alternate thermal application from an economic viewpoint.

It is necessary to develop an efficient solar water heating system for economical usage. Drinking water is a high priority for quality of life. Water resources are coming under increasing pressure due to population growth, wastage, and overuse. The water-borne disease leads to millions of deaths and illnesses.

There are very limited freshwater sources available in the world around less than 1%. Fresh surface water (1%), groundwater (30%), Glaciers(68%). source, a system that is relatively cheap, portable, and depends only on renewable solar energy. The motivation for this project is the limited availability of clean water resources and the abundance of impure water available for potential conversion into potable water, In addition, there are many coastal locations where seawater is abundant but potable water is not available. Our project goal is to efficiently produce clean drinkable water from solar energy conversion. The purification systems available are not easy to get for poor people. So out of different technique which is available one of the cheap and energy-efficient techniques is solar distillation. our solar water purification system consists of five intensification steps over the simple solar purification system. We develop a double basin instead of a single basin, we used diffusion steel. We use a thermosyphon water heating purification system with PCM Chamber.

II. METHODOLOGY

A. *Experimental Setup*

The schematic diagram and experimental setup view of double basin solar still is shown in Fig.4.1.5. The solar still is designed and constructed to increase the efficiency of the pure water output by increasing the rate of evaporation and condensation process. The solar still basin is fabricated by plain carbon steel (0.001 m thick) and it is shaped like a box with dimensions of 0.85 m length, 0.60 m breadth and 0.75 m height. Ordinary window glass (0.004 m thick) is used as a condensing surface. It is fixed completely on the edges of the tank and a slope of 20 °is given to the glass cover, which is almost equal to the latitude of Mumbai. Water depth in the upper and lower basin is maintained at 0.02m as found in experimentation [13][11] that there is maximum efficiency attained at the depth of 0.02m of water in the solar still. UV glue and glass putty are used as a sealing material for filling the gap between the glass cover and solar still in order to prevent the vapor leakage. Plastic graduated bottle is used to collect the coming out distillate.

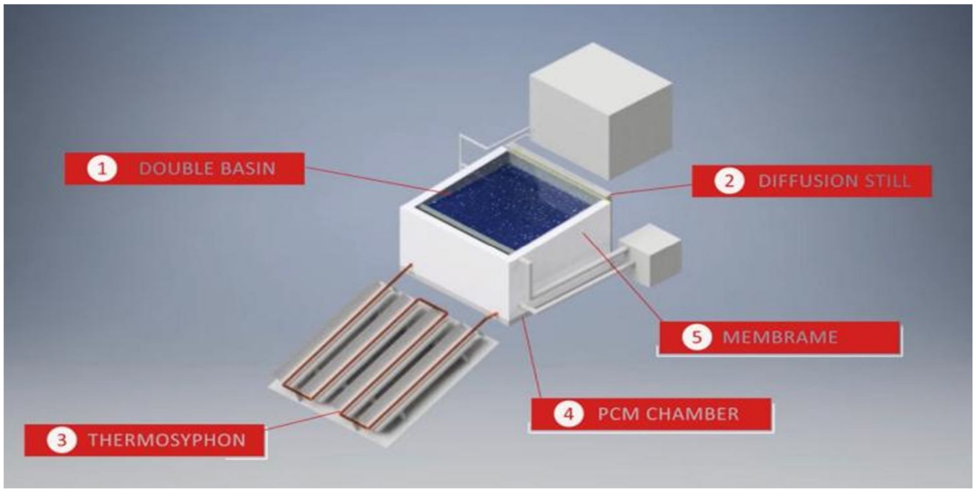

Fig 1. Project Model

The annual yield is at its maximum when the condensing glass cover inclination is equal to the latitude of the place and the optimum collector inclination for a flat plate collector is 28.588, for a condensing glass cover inclination of 19.86° for Mumbai climatic condition. The convective heat transfer coefficient between water and inner condensing cover depends significantly on the water depth of the basin.

The Water from the Dirty water tank get distributed into three channels, one channel goes into the lower tank, the second channel goes into the upper tank and the third channel goes into the diffusion still part The upper basin has a top cover made of glass, with an interior surface made of a blackened material to improve absorption of the sun's rays. Water to be cleaned is poured to partially fill the basin. The glass cover allows the solar radiation to pass into the basin, which is mostly absorbed by the blackened base. The water begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. The heated water vapour evaporates from the basin and condenses on the inner side of the glass cover.

Water which goes onto lower basin, its temperature is not much high so to increase evaporation rate we have used thermosyphon loop which consists of parabolic profile. Water to be cleaned is feed into a partially filled basin. Then water from the basin enters the thermosyphon loop which consists of the parabolic profile which concentrates the sunlight to heat the water. This increases the internal temperature of the copper loop causing water to evaporate and condensate on the inner side of the glass cover. In this process, the salts and microbes that were in the original water are left behind. Condensed water trickles down the inclined glass cover to an interior collection trough and out to a storage bottle.

On the side walls energy which is been wasted is captured by diffusion still part, in diffusion still, there are successive plates, on one plate there is weak and on facing plate it has a clean surface, so the dirty water which is been fade into weak side plate, it is a store there momentary and energy which is extracted by core chamber, it evaporates and diffuses in the thin gap, and eventually it condenses on the facing surfaces and that water is collected in the outlet. In the absence of sunlight this process won't be taking place, so to continue the process we have used phase-changing material, when there is sunlight the phase changing material absorbs the heat and it melts and later in the absence of sunlight will solidify and the energy which will be released will be used to drive the whole process. There are no moving parts and only the sun’s energy is required for operation. So the basic strategy was to increase the rate of evaporation and condensation process.

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Selection Of Materials

SR NO	COMPONENT	MATERIAL	REASON/ PURPOSE	DIMENSION
1	Diffusion Steel	Aluminium sheet	High Thermal conductivity	1 * 1 meter
2	Tanks	Plain carbon with FRP coating	Low thermal conductivity	1 m^2
3	Frame	Mild steel	Stand	1.3” x 1.3”
4	Glass sheets	Glass	Condensing covers	2 * 2 ft
5	Valves	Steel	Adjust flow of water	2” * 3
6	Thermosyphon pipe loop	Copper	High thermal conductivity	1” dia * 6 meters
7	Pipe Elbow	Steel	Giving direction	1” dia 90° Angle
8	Pipe	PVC	Inlet Flow of water	1.5”
9	Pipe	PVC	Outlet Flow	0.75”
10	PCM	Paraffin wax	Chamber below basin	1 m^2
11	Impurities Remover	Plastic /Steel	To remove water dirt	1 unit
12	Parabolic Concentrator	Alluminium sheet	Concentrate rays heat in copper pipes	4 plates
13	Thermosyphon support	Plain Carbon steel	Adjust as a stand	1.5 * 1.5 m
14	Thread 4-way female cross coupling connector	SS	Split supply	1.5” (4 ways)

III. DESIGN OBJECTIVE

The basic objectives of the projects are:

1) To increase the rate of evaporation.
2) To increase the rate of condensation of a system by using PCM and Diffusion steel.
3) It must be low in cost and commercially viable for all people.
4) Increase rate of delivery at the outlet.
5) To get Low PPM water gets at the outlet.
6) To avoid change in properties of a material. A sincere attempt is made to accomplish almost all objectives as mentioned above and make it practically feasible.

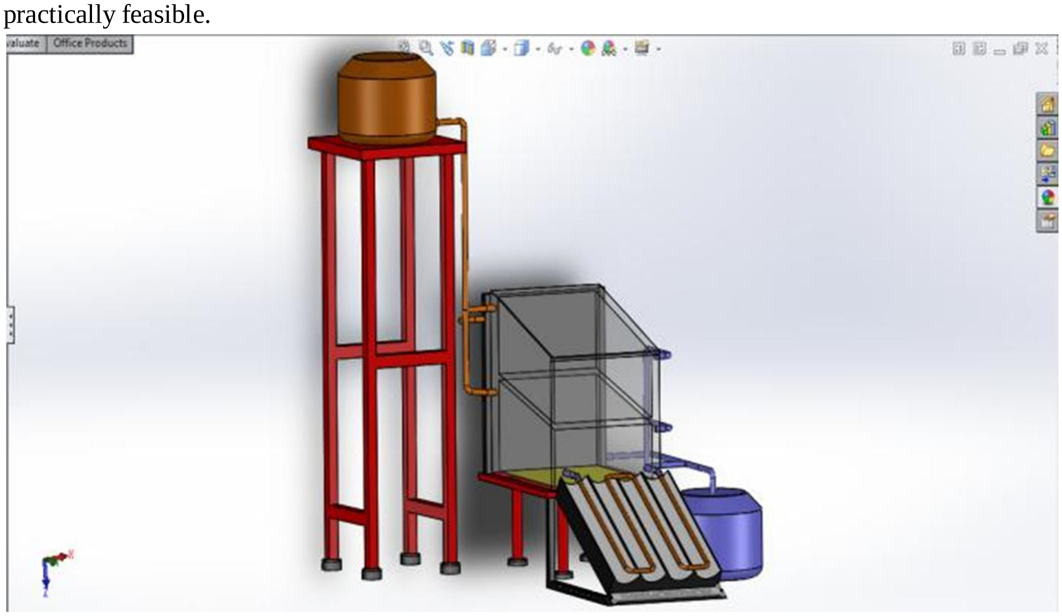

Fig 2. SolidWorks Design of Thermosyphon water purification system

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Fig 3. Actual Model Setup

A. Basin Water Depth

Below Fig. shows the comparison of hourly variation of theoretical and experimental values of distillate output. The maximum distillate output is obtained from lower basin water depth of 2 cm from because It can be observed that the amount of distillate output is inversely proportional to the basin water depth. This is caused by the higher rate of evaporation (due to high rise in temperature) for lower basin water depth [13][14].

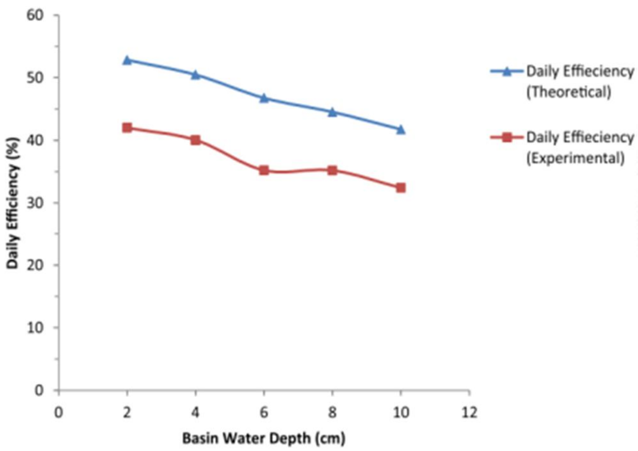

Fig 4. Daily Efficiency v/s Basin Water Depth[13]

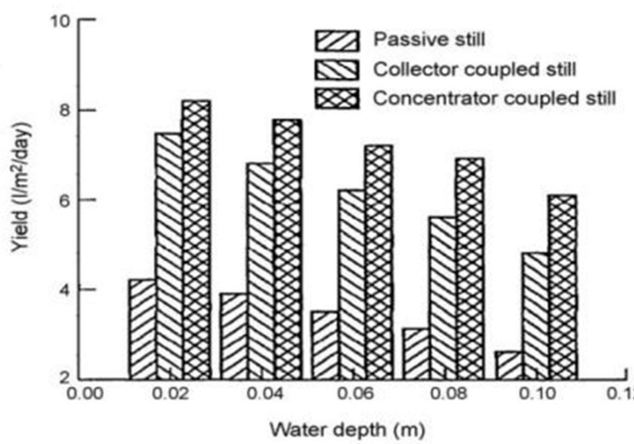

Fig 5. Yield v/s Water Depth[14]

The output of the still is maximum for the least water depth in the basin (2 cm). Also, the increase in water depth has decreased the productivity, while the still productivity is found to be proportional to the solar radiation intensity. Therefore, distillate output decreases with increase in basin water depth in solar still. Therefore we have maintained the water depth at 2 cm in both the basins. For 2 cm basin water depth, maximum theoretical and experimental values of distillate output are obtained.

B. Theoretical Analysis Of Active Solar Distillation System

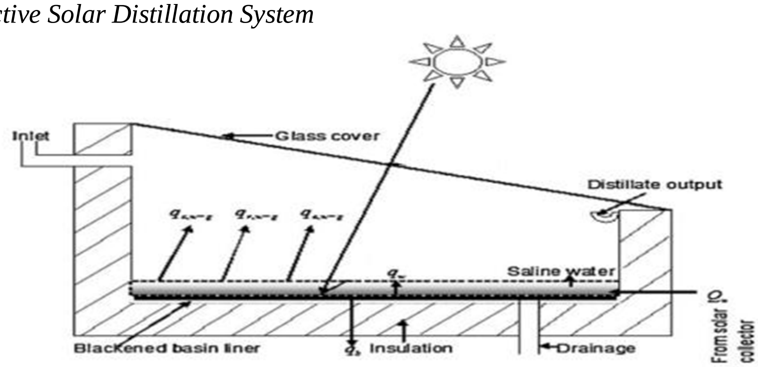

Fig 6. Active Solar Distillation System[16]

C. Temperature and Heat Transfer in Active solar Still

The Theoretical temperature and heat transfer in solar still is calculated for the thermosyphon water solar still. The details of various heat transfers that take place in active solar still are taken from [16].

IV. COMPONENT FUNCTION AND SPECIFICATION

The main components of solar still are:

1) *Basin:* It is the part of the system in which the water to be distilled is kept. It is therefore essential that it must absorb solar energy.
2) *Transparent Cover:* Glazing glass is used and a thickness of 5 mm is selected. 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.
3) *Insulation:* Thermocol is used as an insulator to provide thermal resistance to the heat transfer that takes place from the system to the surrounding.
4) *Sealant:* M seal and is used as a sealant to make the distiller leakproof and air-tight. UV Glue is used to join Metal to Glass.
5) *Supply And Delivery System:* Four holes are made in the basin, one for supply and two for delivery.
6) *Thermosyphon Loop:* It is made of a Cooper loop and mounted on a parabolic profile.
7) *Diffusion Steel:* It is made of successive Aluminium plates.

a) *Phase Changing Material:* This material during the phase change absorbs thermal energy from the surrounding to change its state, and in the reverse process, the stored energy is released to the surrounding. . A PCM normally absorbs and releases thermal energy 5–14 times more than other storage materials such as water or rock. PCMs can store thermal energy in one of the following phase transformation methods: solid-solid, solid-liquid, solid-gas, and liquid-gas. Paraffin-based phase change materials. Paraffin is usually a mixture of straight-chain n-alkanes with the general formula:- C_nH_{2n+2}. In sensible heat storage (SHS) systems, heat can be stored by increasing the temperature of a material. Hence, this system exploits both the temperature changes and the heat capacity of the material to store energy. The amount of heat stored in this system depends on the specific heat, temperature differences, and amount of material; thus it requires a large number of materials, whereas Latent heat storage (LHS) is generally based on the amount of heat absorbed or released during the phase transformation of material.
b) *Thermosyphon Loop:* Thermosyphon Loop consists of a Parabolic trough and copper pipes. A parabolic trough concentrator (PTC) comprises a cylindrical concentrator, of parabolic cross-sectional shape, and a circular cylindrical receiver located along the focal line of the parabola. It reflects direct solar radiation onto a receiver tube located in the focal line of the parabola. Since the collector aperture area is bigger than the outer surface of the receiver tube, the direct solar radiation is thus concentrated. The parabolic trough reflector is a solar thermal energy collector designed to capture the sun's direct solar radiation over a large surface area and focus, or more generally "concentrate it" onto a small focal point area increasing the solar energy received by more than a factor of two which means more overall heat per square meter of the trough. The shape of concentrating solar collectors must be specifically designed so that all the incoming sunlight reflects off the surface of the collector and arrives at the same focal point no matter what part of the collector the sunlight hits first. Concentrating solar collectors for residential applications are usually a "U-shaped" parabolic trough (hence their name) that concentrates the sun's energy on an absorber heat tube called a receiver that is positioned along the focal point axis of the reflective trough.

Fig 7. Thermosyphon Copper Loop with parabolic concentrator

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V. WORKING PRINCIPLE

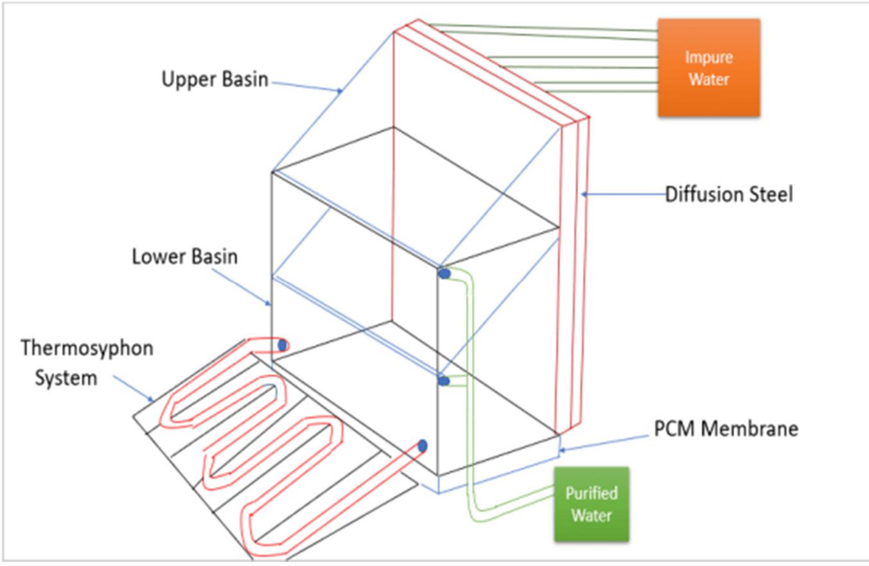

Fig 8. Working Principle of Thermosyphon water purification system

The Thermosyphon water purification works on the principle of solar distillation. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapor rises, condensing on the glass surface for collection. Saline water is filled in the black painted lower basin and upper basin. This is enclosed in a completely air-tight surface. A sloping transparent cover is provided at the top. Then solar radiations are allowed to fall on it. Solar radiation is transmitted through the cover and is absorbed in the black lining. The solar radiation fall on the upper basin which increases the temperature of water and evaporation takes place. Water from the lower basin enters the copper loop. The thermosiphon loop is designed so that due efficient amount of solar radiations the water in the copper loop get heated. This increases the internal temperature of the copper loop causing the saline water to evaporate leaving behind all the salt contents, insecticides, herbicides, bacteria, viruses, etc. The resulting vapour rises and condenses as pure water on the underside of the cover and is collected in the condensate channel due to the inclination provided to the glass covers. Finally, freshwater is obtained.

A. *Applications*

1) High use in Rural areas.
2) High mineral water gets than any RO water purifier (as output water TDS of 130-150 ppm is achieved).
3) It is used in boiler and furnaces industry.

VI. OBSERVATIONS AND RESULT

A. *Observation*

Hourly variation of: **Upper basin water temperature * Lower basin water temperature *Upper Condensing cover temp *Lower Condensing cover temperature*

Hourly variation of theoretical values of basin water the temperature has been shown in Fig.9.

It was observed that the values of maximum temperatures were at around (11:00 to 13:00 h). The maximum theoretical value of temperature attained at around 12:00 his 89°C, 81°C, 76°C, 66°C. For Upper basin water temperature, Lower basin water temperature, Upper Condensing cover temp, Lower Condensing cover temperature respectively. It was found that maximum yield was obtained during the period of the high-temperature difference between the basin water and condensing material. There is maximum temperature in the lower basin as it is attached to the thermosyphon system. The water from the inlet of the basin is initially at low temperature but the water moves through the hole provided in the lower side and follows the loop. Therefore extra energy is transferred to the lower basin water. The condensing cover in the upper basin is an aluminium sheet due to which heat conduction is good resulting in the transfer of heat from the lower basin to the upper basin. The majority of temperature in the upper basin mainly depends upon direct heat received from sunlight and some heat received from the lower basin. These result in the lower temperature of the upper basin when compared to the lower basin.

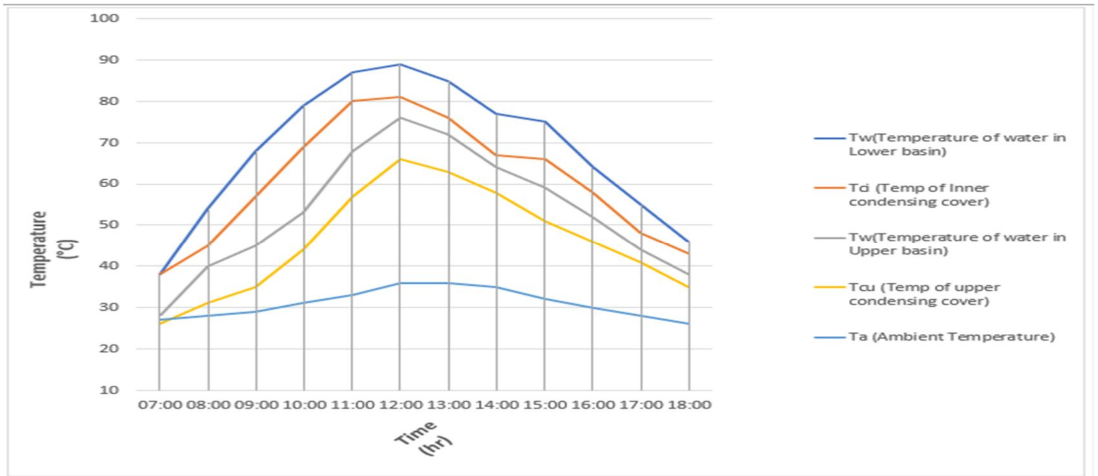

Fig 9. Theoretical Hourly Temperature Calculated

Glass temperature is another main parameter, which affects the performance of the solar still. The rate of evaporation increased with reduction of glass temperature. The rate of evaporation of water from a water surface will be higher than the rate of release of heat from the glass cover to ambient by convection and radiation processes. If the heat loss from glass cover to ambient can be increased and that heat loss is used for further distillation, then overall efficiency of the distillation unit under active modes of operation can be increased significantly, as in the case of double basin solar still. This can be obtained by flowing the water over the glass cover for fast heat transfer through the lower glass cover and then condensing the evaporated water from the upper glass cover as distillate.

In the Double effect still coupled with parabolic concentrator,

1) The temperature of the water in the lower basin is increased in comparison with single effect distillation due to the reduced upward heat losses.
2) The hourly output in the lower basin is reduced due to the reduced temperature difference between the water and glass temperatures. However, the overall output is increased due to reutilization of the latent heat of evaporation in the second effect.
3) The hourly yield from the lower basin increases with increase of flow velocity due to the decrease in the lower glass temperature. It is due to the fact that the lower glass cover temperature decreases due to the fast removal of the latent heat of vaporization.
4) The evaporative heat transfer coefficient is a strong function of the operating temperature range. The convective and radiative heat transfer coefficients does not vary significantly.

B. Hourly variation of distillate output (Yield) in Litre/m2

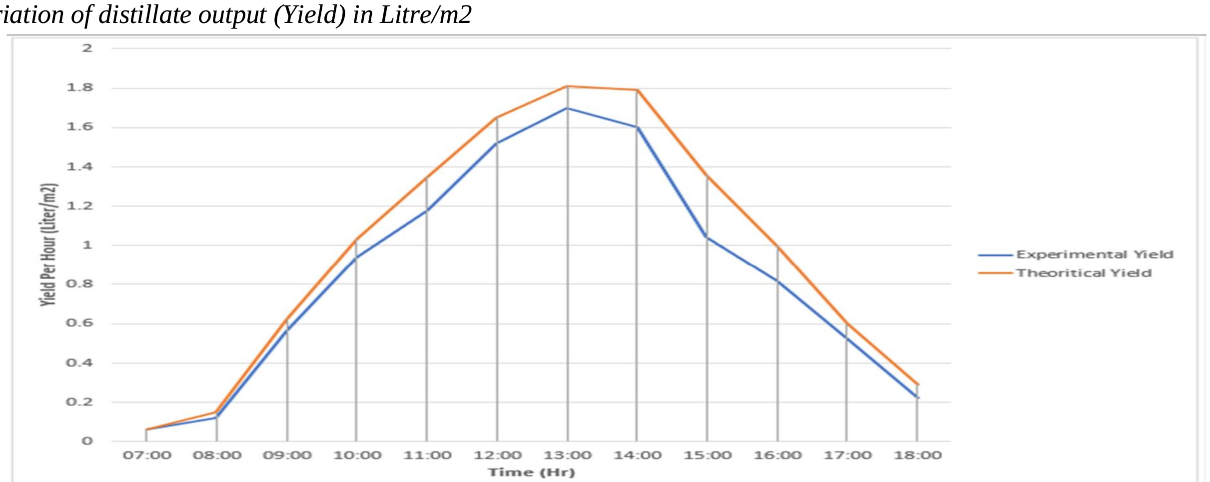

Fig 10. Theoretical & Experimental Yield per hour (litre/m2)

From Fig. 10, It can be observed that theoretical and experimental data are similar with each other and can be agreed. The Maximum Hourly yield is achieved during 12:00 to 14:00 hrs. The theoretical data showed that maximum yield of 1.082 litre/m2/hr. can be achieved but experimentally we have achieved 1.7 litre/m2/hr. which is quite nearby to the theoretical part.

However we have received total yield of 10.3 litres/m2 during the full day and the efficiency of the model is increased greater than 60% due to various factors like thermosyphon system, Diffusion steel and PCM chamber attached to increase the effect of evaporation.

The heat transfer coefficients mainly depends on the shape of the condensing cover, material of the condensing cover and temperature difference between water and inner glass cover.

In the Double effect still coupled with parabolic concentrator,

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4) The evaporative heat transfer coefficient is a strong function of the operating temperature range. The convective and radiative heat transfer coefficients does not vary significantly.

C. Result

Thermosyphon solar still purifier productivity : 10.31 lt/m^2/Day

1) *Purity:* Recommended TDS (for drinking purpose) : <500 ppm
2) *TDS:* Around 130-160 ppm

D. Comparison Of Present Research With Previous Research Work

Sr No.	Authors	Type of solar still	Productivity ($kg/m^2/day$)	Location/Latitude	Season/Month
1	Yadav and Prasad (1990) [8]	Single basin single slop	5.3	Delhi, India/ 28.37° N	Summer
2	El-Sebaii et al. (2009) [9]	Single basin single slop	5.5	Jeddah, Saudi Arabia/ 21° N	Summer
3	Sanjay Kumar & Tiwari [10]	Double effect solar still	7.51	New Delhi, India 28.37° N	Summer
4	Our Present Final year project	Thermosyphon purification system	10.31	Mumbai, India 19.86°N	Summer

Table No 2 Comparison the present work with earlier research work.

A comparison between productivity values obtained by other researchers and those obtained in the present work is shown in Table 2. Yadav and Prasad [35] obtained theoretically the productivity of single basin solar still as 5.3 Kg/m2/day for basin water depths of 2 cm at Delhi, India in the summer season. For Double effect still, Sanjay Kumar & Tiwari obtained productivity of 7.51 Kg/m2/day. We have obtained higher yield of 10.31 Kg/m2/day as the hybrid system is connected with diffusion still on back, Thermosyphon loop attached to the lower basin to increase the temperature of water in the basin and PCM chamber is connected to obtain the nocturnal output.

VII. CONCLUSION

In this project, we have found numerous point which needs to be booked into while designing the thermosyphon water purification system. The Double slope double basin solar still attached with thermosyphon system was fabricated and investigated under the climatic conditions of India at Mumbai (Latitude: 19°6'6.49"N, Longitude: 72°53'25.27"E). Experimental results for a number of parameters were obtained for basin water depths of 2 cm and these results were compared with the results of theoretical thermal model of solar still. On the basis of present study, the following conclusions can be drawn.

1) The maximum theoretical and experimental values of basin water temperatures are 98 °C and 82 °C at around 13.00 h respectively in the lower basin.
2) It is observed that the values of convective and radiative heat transfer coefficients are much lesser than the value of the evaporative heat transfer coefficient.
3) maximum theoretical and experimental values of distillate output obtained are 1650 gm respectively, at 1 p.m.
4) The theoretical and experimental values of cumulative distillate output for 24 h at lowest basin water depth (2 cm) are 10.31 kg/m2/day
5) Nocturnal output is increased with the use of PCM chamber. It releases energy in the off sunshine hours and it is utilized by the basin attached above it.
6) Theoretical and experimental daily efficiency is higher than 60%.
7) When considering the attenuation factor for different basin water depths, the distillate output is increased around 4% than without consideration of the attenuation factor for different basin water depths.
8) The theoretical values of Lower basin water temperature, Lower condensing cover temperature, upper basin water temperature and upper condensing glass cover temperature are compared and it was found that temperature in the lower basin is higher the water passes from copper pipe loops.
9) The extra energy released from lower basin is efficiently utilized from the upper basin and side diffusion still make the total yield output to cross 10 kg/m2 per day mark.

VIII. ACKNOWLEDGEMENTS

We take the chance to direct our sincere thanks and gratitude to Hon. Principal, Prof. Dr. Aqueel Ahmed Shah and Management of Theem College of Engineering, for providing motivation and much support throughout our project work. We would like to gives our heartfelt thanks towards our Prof. Akhtarhusen Momin for his help, guidance, and encouragement, during the Project. Also, we are heartily thankful to all Lecturer in Engineering and professors in the Mechanical Department. We were motivated by the encouragement of our professors and this made us complete our work under their oversee.

IX. CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this article.

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