A Dissertation on

“Experimental Investigation and Thermal Analysis of Solar Still”

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CERTIFICATE

This is to certify that *Mr. Prasad Chandrakant Kakade, Mr. Amar Ravindra Kakade, Mr. Atharva Chandrashekhar Kale, Mr. Amol Madhukar Gaikwad* has successfully completed the dissertation entitled "**Experimental Investigation and Thermal Analysis of Solar Still"** under my supervision, in the partial fulfillment of Bachelor of Engineering Mechanical Engineering of Savitribai Phule Pune University.

Date:

Place:

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SEAL

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Sincerely,

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Place: Pune

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PROJECTEE

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Abbreviation

Sr.no	Abbreviation	Description
1	PCM	Phase Change Material
2	GI Sheet	Galvanized Iron
3	PV	Photo Voltaic
4	TSS	Tubular Solar Still
5	CNT	Carbon Nano Tubes
7	NF	Nano Fluids

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ABSTRACT

Human life is based on water. Safe drinking water is one of our fundamental needs. Water is one of the most abundant resources on earth covering 75% of the planet's surface. About 97% of the earth's water is salt water in the oceans, and a tiny 3% is fresh water.

Sea water contains large amount of salts. The salts exist in the form of chloride, sulphate, sodium, magnesium, potassium etc. Chloride and sulphate contribute to about 55% and 31% of sea salts respectively. Eating small quantities of saline water are not harmful, but more can be dangerous, ultimately producing fatal seizures, heart arrhythmias and kidney failure.

Therefore, there is need to purify the water to make suitable for drinking. It would be feasible to address the water-shortage problem with seawater desalination; however, the separation of salts from seawater requires large amounts of energy which, when produced from fossil fuels, can cause harm to the environment. Therefore, there is a need to employ environmentally friendly energy sources in order to desalinate seawater.

This report covers introduction into desalination, comparative analysis of current desalination technologies. Some general concepts are given for the proper selection of desalination method. Description of designed desalination device is given in detail. After that, its construction, total cost, performance, efficiency and results are given here. Device maintenance, drawbacks and few related points etc. are also studied.

Chapter 1

INTRODUCTION

Water is essential to life. Next to oxygen, fresh water is the most important substance for sustaining human life. Access to water is considered to be a basic human right. However, the increased use and misuse of this resource by the growing population and increasing industrial activities may lead to a situation whereby countries need to reconsider their options with respect to the management of its water resources. About 1.2 billion people in the world lack access to potable water, over 2.6 billion without access to adequate sanitation, and 1.8 million children killed each year by preventable water-borne diseases many of these people live within the poorest countries of the world.

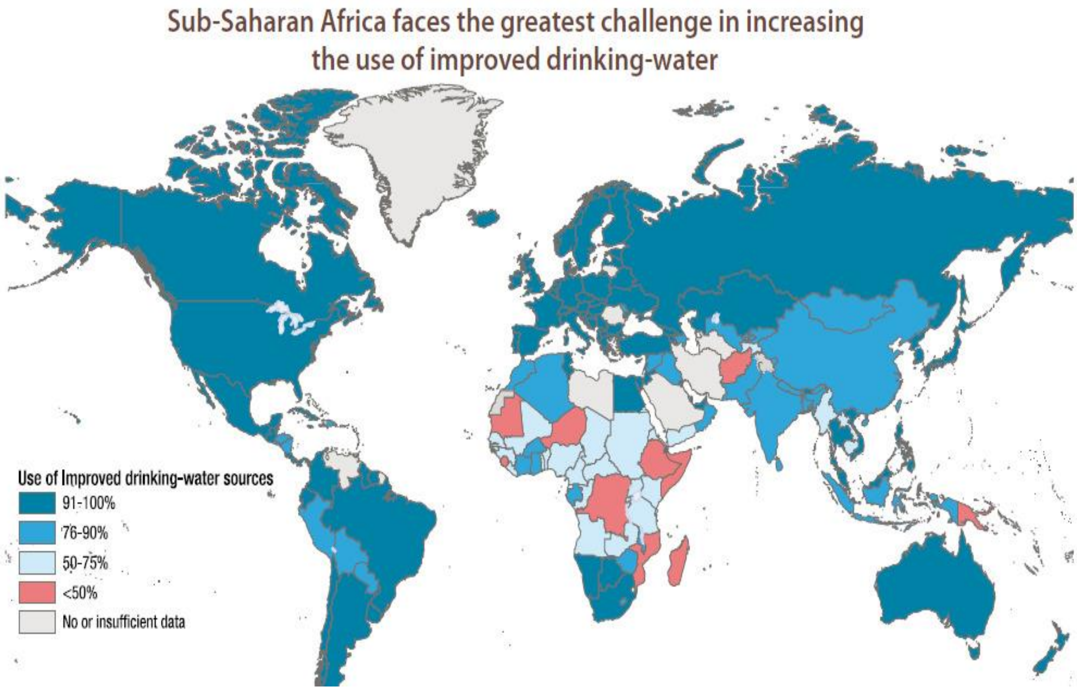


Figure 1.1: Global distribution of drinking water availability.

Conventional solar stills are one method of supplying potable water through using a renewable and free energy source. The solar still is point-of-use technologies that have been proven to remove pathogens, heavy metals and reduce salinity. Despite the fact that this technology can provide a cheap source of potable water they have the disadvantage that they are on average only 30% efficient and require 2m2 to provide for one person's daily needs. The solar stills have often been used in the tropics where there is abundant supply of solar energy.

In this work, a basin-type solar still was designed to investigate the effect of phase change material on the performance of conventional solar still using actual environmental conditions.

Basically, the still consists of a black-lined shallow basin of saline water enclosed by a transparent cover with sloping sides. Solar radiation passing through the transparent cover is absorbed by the brine and the black basin liner. This radiation is changed to heat by absorption, which serves to warm the brine. The warm brine partly evaporates and humidifies the air above the surface, thereby reducing the density of the air and causing it to circulate upward.

The moving air comes in contact with inner surface of the relatively cool transparent cover, and part of the humidity condenses thereon. The liquid condensate forms a film and flows to the base of the cover, from where it drips into the condensate trough and is conducted to the outside of the enclosure. The cooled air returns to the surface of the warm water to repeat the process of humidification. The circulation of air is thus due entirely to free convection.

Many adaptations have been made to the solar still design to improve the efficiency, however not so much attention has been paid to phase change material. This study will investigate the use of phase change material to improve the potable water yield from a conventional solar still. The next four sections of this thesis will cover the literature review of solar desalination systems and more importantly the various renewable systems available and some research on phase change material; this will be followed by the method, which is the storyline of the experiment conducted on the roof top of the James Weir building, University of Strathclyde, Glasgow involving the design, build and test phases of the different variables of the still; followed by results and discussion of the data acquired as well as the analysis of this data; Finally, conclusions will be made and recommendations regarding future improvements will be proposed.

The purpose of this research was to investigate the effect of phase change material in the conventional solar still design. The results were correlated and analysed for subsequent trends. It was hoped that the phase change material would improve the overall potable water yield of the solar still.

1.1 Problem Statement

Water is life, and the threat of unsustainable means of potable water supplies has led to the reviews of various renewable energy sources to create a cleaner and more efficient solution for potable water supply. Various modular technologies existed, in which potable water can be produced, but these have proved to be quite expensive as large and very complex designs are involved. Because this problem is prevalent in the world's poorest countries, there is need for the technology to be simple in design, affordable and sustainable.

1.2 Solar Radiation:

Solar radiation is a free and renewable source of energy. The sun is the primary source of solar radiation. It emits radiation at an equivalent black body temperature of about 6000 K with a constant intensity outside the earth's atmosphere [q]. Solar radiation is radiant energy emitted by the sun. About half of the radiation is in the visible short-wave part of the electromagnetic spectrum. The other half is mostly in the near-infrared part, with some in the ultraviolet part of the spectrum. Irradiance is a measure of the rate of energy received per unit area, and has units of Watts per square meter (W/m^2).

1.3 Peak Sun Hours:

Peak Sun Hours is the number of hours required for a day's total solar irradiation to accumulate at peak sun condition. An average day may have only one or two actual hours at peak sun condition, but the total irradiation for a day may be expressed in units of peak sun hours by dividing by 1000 W/m2 (peak sun irradiance).

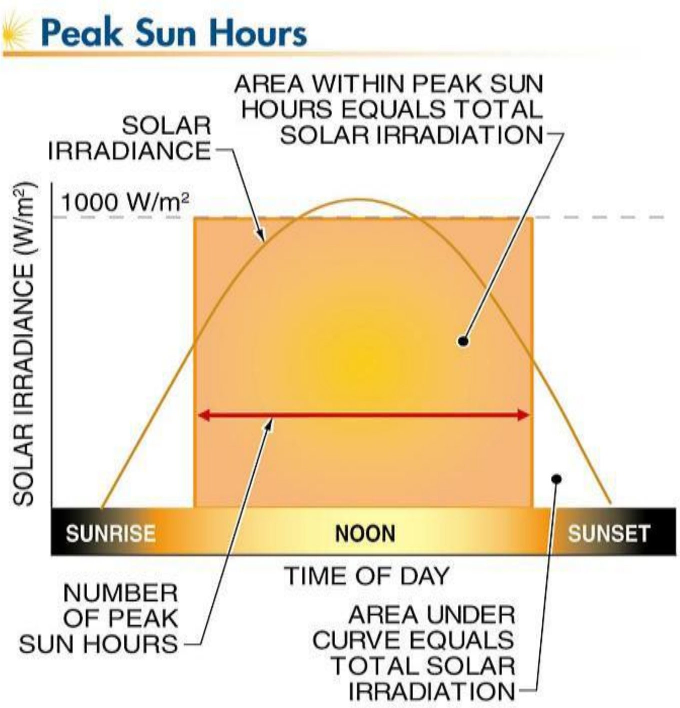


Figure 1.3:Peak Sun Hours

1.4 Solar Power Desalination:

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×1011MW. Which is many thousands times larger than the present all commercial energy consumption rate on the earth [q]. Thus in principle, solar energy could supply all the present and future energy needs of the world on a continuous basis. This makes it one of the most promising of all the unconventional energy sources. In addition to its size, solar energy has two other factors in its favour. Firstly, unlike fossil fuels and nuclear power, it is an environmentally clean source of energy. Secondly, it is free and available in adequate quantity.

1) Solar Powered Distillation is one method of desalination. Distillation has the advantage of using thermal energy, such as sunlight, thus saving electricity costs.
2) With technology constantly improving, and current prices of conventional fuel sources increasing, it can be safe to say that solar-assisted desalination will be one of the most efficient and affordable options in the near future.

3) Desalination powered by renewable energy: environmentally friendly and de-centralized solution for sustainable water supply.
4) Solar distillation is a relatively simple treatment of brackish water supplies. This process removes salts and other impurities.

Figure 1.4: Desalination process

1.5 Objectives:

1) To design and develop a solar still.
2) To improve the productivity of solar still using phase change material
3) To study the effect of flow rate and Spacing between condensing cover and water surface on the performance of solar still.

1.6 Scope:

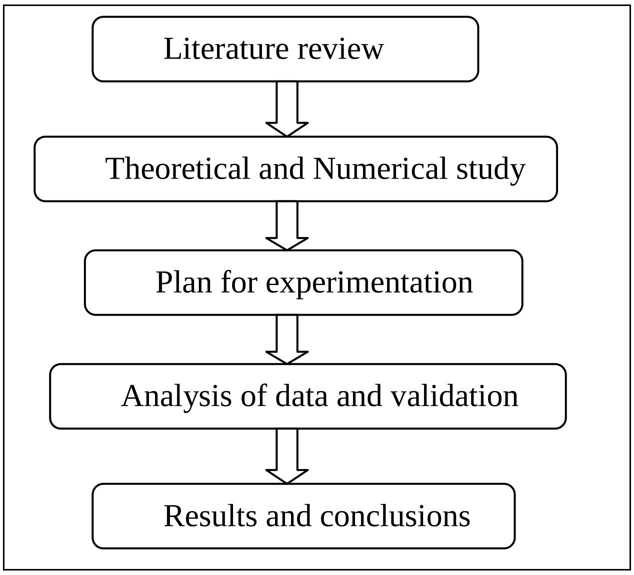
The severity of fresh water shortage can easily be gauged by the fights that have erupted over water in the recent past in India and outside. Statistics emphasize the same at least 40% of the world's population lives without drinking water and roughly 80 000 habitations across the planet have no source of safe water. Out of total 575 000 Indian villages, about 162 000 faces problems of brackish, contaminated water and scarcity of fresh water. To get more water out of the system to meet the increasing demand of fresh water more research has to carry out to improve productivity and efficiency of the solar stills.

1.7 Challenges identified:

Despite of large efforts carried out on solar distillation to improve productivity and efficiency, there are some challenges like

1) Lower yield
2) Bulkiness and High initial cost
3) Optimization of spacing between condensing cover and water surface,
4) Thermo physical properties of basin material,
5) Flow rate, insulation material, and its thickness, which need to be improved to make this technique efficient in practical utilization. Also, certain inherent flaws in these devices like leakage of water vapour through joints and glass sealing of solar stills and the delivery of a small quantity of desalinated water has to be improve.
6) Slope of collector pipe

1.8 Methodology:



Chapter No: 2

LITERATURE REVIEW

Hamdy Hassan, Saleh Abo-Elfadl has experimented on *"Effect of the condenser type and the medium of the saline water on the performance of the solar still in hot climate conditions"*(May 2017)This paper presents an experimental work to study the effect of the condenser and the medium of saline water types on the performance of the solar still. Single slope solar still facing the south is used in this work. Also, four types of the condenser are tested: (i) glass, (ii) aluminum plate, (iii) aluminum heat sink with pin fins, and (iv) aluminum plate covered with an umbrella. Moreover, four mediums of the saline water inside the basin are examined: (i) only saline water in the basin, (II) Layers of black steel fibres in the basin, (iii) saturated sand with saline water, and (iv) mixture of sand and black steel fibres saturated with saline water. The solar still of only glass walls and only saline water in the basin is taken as a reference case. The performance of the other cases is referred to the reference case. The results indicate that using heat sink condenser increases the temperature of the saline water. Also, it increases the temperature difference between the condenser and the saline water relative to using glass condenser. Using an umbrella of 20 cm wide at the top of the aluminium plate condenser decreases the daily productivity by 26%. Increasing the umbrella wide to 40 cm decreases the daily productivity by 31%.[1]

T. Rajaseenivasan, R. Prakash, K. Vijayakumar, K. Srithar has worked on *"Mathematical and experimental investigation on the influence of basin height variation and stirring of water by solar PV panels in solar still"*(April 2017) A detailed evaluation on height variation (0.45 m to 0.15 m) between saline water surface and glass cover is discussed in this work. Impact of height variation is analysed with different thermal models and validated with experimental results. Best basin height is selected and further inquiries are conducted by creating turbulence in the saline water using four stirrers. The stirring action is performed by motors operated with a solar photovoltaic panel. Investigations are continued by placing the paraffin wax and charcoal in the basin. Consequence of the test shows that the fresh water production rate of solar still accelerates with the reduction in height. The stirrer action escalates the evaporation rate in solar still and thereby 30% increase in distillate compared to the conventional solar still. Nocturnal fresh water output of the solar still augments with the energy storage materials in basin. The peak daily yield is collected as 5.23 kg/m2 day for solar still with the combination of stirrer and paraffin wax as energy storage material in the basin. Theoretical result agrees well with the experimental results.[2]

Mohamed Elashmawy have worked on *"An experimental investigation of a parabolic concentrator solar tracking system integrated with a tubular solar still"*(February 2017)Where research carried on, The study describes the performance of three different experiments under the climatic conditions of Hail city (27.5°N, 41.7°E) in Saudi Arabia by using a tubular solar still (TSS) with a rectangular trough filled with a black cloth and saturated by raw water in the first experiment; a TSS with a half cylindrical trough without clothing in the second experiment, while in the third experiment TSS of the second experiment was integrated with a parabolic concentrator-solar tracking system(PCST-TSS). Results show a high potential of using PCST-TSS compared to conventional TSS. [3]

H. Sharon , K.S. Reddy , D. Krithika , Ligy Philip have worked on *"Experimental investigation of tilted solar still with basin and wick for distillate quality and enviro-economic aspects"*(January 2017) Where research carried on Tilted wick type and stepped solar stills are well known for their increased distillate yield compared to basin type stills. In this study experiments were conducted on tilted solar still with basin and tilted solar still with wick to assess their performance, distillate quality, environmental benefits and economic feasibility. Yearly average thermal and energy efficiency was around 41.06% and 3.06% for the unit with basin and 33.83% and 2.88% for the unit with wick. Energy payback time of the unit with basin was around 2.80 yrs and it can prevent 17.65 tons of CO2 emission during 20 yrs of life time. Distillate production cost was around 0.026 USD/L (Rs. 1.74/L) and 0.046 USD/L (Rs. 3.08/L) for an interest rate of 5% and 12%, respectively. Tilted solar still with basin has superior performance compared to that of unit with wick and can produce 21.76 L of distillate/USD invested on it.[4]

Hiroshi Tanaka, Koji Iishi has worked on *"Experimental study of a vertical single-effect diffusion solar still coupled with a tilted wick still"*(September 2016)A single-effect diffusion still, instead of a multiple-effect diffusion (MED) still, combined with a tilted wick (TW) still was investigated experimentally under actual weather conditions to investigate whether the natural convection can transport the vapour from the TW still to an MED still adequately. It was found that the single-effect still can be heated by vapour from the TW still and solar radiation absorbed on the single-effect still. From the experiments in summer and autumn, it was found that an MED still can be heated in both seasons whether the MED still absorbs solar radiation directly or not. The experimental results agreed with the calculation results. The total daily amount of distillate, $\Sigma_{md,total}$, did not correlate with the daily horizontal solar radiation, ΣG_{day}, but strongly correlated with daily solar radiation incident on the still, ΣG_{still}. The maximum of $\Sigma_{md,total}$ obtained in experiments was about 4.88 kg/m2 day when ΣG_{day} and ΣG_{still} were 13.6 and 18.4 MJ/m2 day, respectively.[5]

S.M. Shalaby , E. El-Bialy , A.A. El-Sebaii *"An Experimental investigation of a v-corrugated absorber single basin solar still using PCM"*(August 2016)in this paper, a new design of a v-corrugated absorber solar still with built-in phase change material (PCM) is presented. This design allows for the expansion of melting wax through a net of tubes extended inside the storage tank. The system is tested with and without the PCM using different water masses. Adding wick over the corrugated plate using PCM is also investigated. Paraffin wax is chosen as a PCM due to its medium storage, safety, reliability, uniform melting and moderate cost. The experimental investigation shows that the solar still with using the PCM beneath the corrugated plate with less basin water mass achieves the best thermal performance among other studied configurations. Using the PCM causes a little decrease in the daylight productivity with a considerable increase in the still overnight productivity. The daily productivity of the still with the PCM when mw = 25 kg is 12% and 11.7% better than those for the v-corrugated still without the PCM and with the PCM using wick, respectively. Cost analysis is also performed where the cost per litre (CPL) for the still without PCM, with PCM and with PCM using wick are estimated as 0.07182, 0.08369 and 0.09558 $/l, respectively.[6]

Y.A.F. El-Samadony ,Wael M. El-Maghlany , A.E. Kabeel ***"Influence of glass cover inclination angle on radiation heat transfer rate within stepped solar still"*****(April 2016)** In the present work, a new theoretical analysis of the radiation heat transfer rate inside a stepped solar still is presented. Radiation shape factor between hot saline water and glass cover for a stepped solar still is computed. The effect of taking the radiation shape factor into consideration is qualitatively and quantitatively determined. The effect of glass cover inclination angle (from 10° to 70°) and solar insolation (from 200 to 1200 W/m2) on stepped solar still productivity; taking into account the radiation shape factor is investigated. It is found that the influence of the radiation shape factor on the thermal performance predictions is significant. Moreover, the productivity of the solar still is found to be sensitive to the radiation shape particularly at low solar insolation and/or high glass cover inclination angle (i.e. latitude angle of the site) and vice versa. Finally, fair agreement between the present theoretical work and the previous experimental result has been accomplished.[7]

A.E. Kabeel, Mohamed Abdelgaied ***"Improving the performance of solar still by using PCM as a thermal storage medium under Egyptian conditions"*****(April 2016)** In this paper the objective of the present work is to improve the performance of a solar still through increasing the productivity of freshwater. In order to improve the performance of a solar still, a phase change material (PCM) was added as a heat storage medium. Two solar stills were designed, constructed and tested in the present experimental study to compare the productivity of the solar desalination system. One of them is a solar still with PCM and the other is the conventional solar still. The experimental results show that, the daily freshwater productivity for solar still with PCM is higher than that of conventional solar still. The results show that the daily freshwater productivity for solar still with PCM is 67.18% higher than that of the conventional solar still. Also, the solar still with PCM is superior in daily freshwater productivity (67%–68.8% improvement) compared to a conventional solar still in the period from June to July 2015 under the ambient conditions of Tanta city (Egypt). In this case study the estimated cost of 1 L of distillate water reached approximately 0.24 LE (0.03 $) and 0.252 LE (0.032 $) for solar still with PCM and conventional solar still, respectively.[8]

Mohamed Asbik, Omar Ansari, Abdellah Bah, Nadia Zari, Abdelaziz Mimet, Hamdy El-Ghetany ***"Energy analysis of solar desalination still combined with heat storage system using phase change material (PCM)"*****(March 2016)** Studied the energy analysis of a passive solar still combined with heat storage system is presented in meteorological conditions taken on 15th of June 2011 at Errachidia city (Latitude: 31°58'N, Longitude: 4°20'W, Morocco), to determine the magnitude of energy losses during the heat storage/retrieve period. Paraffin wax is used as phase change material (PCM) to store/retrieve energy in the process of changing the aggregate state from solid to liquid. The energy balance equation for each element of the desalination unit as well as for the PCM is formulated and numerically solved. The variations versus time of temperature within PCM, the energy destruction of solar still and that of PCM medium, the pure water productivity and energy efficiency are shown in the obtained results. Effects of the influencing parameters (the thickness of the PCM medium, the ambient air velocity and the brackish water depth) on the energy destruction (entropy generation) are highlighted. Moreover, the latent heat storage increases the water productivity and reduces the energy efficiency**.**[9]

A.E.Kabeel , Mohamed Abdelgaied, M.Mahgoub ***"The performance of modified solar still using hot air injection and PCM"*****(February 2016)** This paper reports the details of a double passes solar air collector–coupled modified solar still, with Phase Change Material (PCM), have been experimentally investigated to enhance the freshwater productivity. The influence of the injected hot air on the performance of a modified still, with PCM, is investigated. A comparison between a modified still, with both PCM and hot air injection, and the conventional still is carried out to evaluate the enhancement in the freshwater productivity. The experiments were carried out under the same atmospheric conditions. The experimental results show that, the freshwater productivity approximately reached 9.36 (L/m2 day) for the double passes solar air collector–coupled modified solar still, with PCM, while its value is recorded 4.5 (L/m2 day) for the conventional still. The freshwater productivity of the double passes solar air collector–coupled modified solar still with PCM is 108% higher than that of the conventional still on average. This percentage is obtained during the period from June to July 2015 under the Egyptian climatic conditions.[10]

S.A. El-Agouz , Y.A.F. El-Samadony, A.E. Kabeel in paper entitled *"Performance evaluation of a continuous flow inclined solar still desalination system"*(November 2015) studied of the performance evaluation of a continuous water flow inclined solar still desalination system is performed. Three models are studied for inclined solar still desalination system with and without water close loop. The effects of the water mass, water film thickness, water film velocity and air wind velocity on the performance of the three models are studied. The results show that the inclined solar still with a makeup water is superior in productivity (57.2% improvement) compared with a conventional basin-type solar still. The inclined solar still with a makeup (Model 3) gives the highest performance while Model 1 gives the lowest performance. Finally, the water film thickness, and velocity as well as wind velocity plays important roles in improving the still productivity and efficiency.[11]

Hitesh N.Panchal*"Enhancement of distillate output of double basin solar still with vacuum tubes"*(July 2015)In this research paper, attempts are made to make a double basin solar still. The overall size of the lower basin used is 1006 mm × 325 mm × 380 mm and the outer basin is 1006 mm × 536 mm × 100 mm. Black granite gravel is used to increase the distillate output by reducing the quantity of brackish or saline water in both basins. Several experiments have been conducted to determine the performance of a solar still in climate conditions of Mehsana (latitude of 23°59′ and longitude of 72° 38′), Gujarat. Here, three conditions used to determine the performance of double basin solar still like a double basin solar still alone, double basin solar still with black granite gravel, double basin solar still with vacuum tubes and double basin solar still with vacuum tubes and black granite gravel. Experimental results and comparison with other researchers show that, the daily distillate output increases by coupling vacuum tubes and by coupling vacuum tubes and black granite gravel to 56% and 65% respectively.[12]

T. Elango , A. Kannanb, K. Kalidasa Murugavel, *"Performance study on single basin single slope solar still with different water nanofluids"*(March 2015)compared the performance of single basin single slope solar still with and without water nanofluid. Water nanofluids of Aluminium Oxide (Al_2O_3), Zinc Oxide (ZnO), Iron Oxide (Fe_2O_3) and Tin Oxide (SnO_2) of different concentrations were characterized for thermal and physical properties and suitable nanofluids were selected for performance testing in solar still. Two experimental stills of the same basin area have been fabricated and testedwithwater and different nanofluids simultaneously. The still with Aluminium Oxide (Al_2O_3) nanofluid has 29.95% higher production and the still with Zinc Oxide (ZnO) and Tin Oxide (SnO_2) nanofluids has 12.67% and 18.63% more production respectively than the still with water.[13]

Miqdam T Chaichan, Hussein A Kazem *"Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM)"*(March 2015) This paper investigates usage of thermal energy storage extracted from concentrating solar heater for water distillation. Paraffin wax selected as a suitable phase change material, and it was used for storing thermal energy in two different insulated treasurers. The paraffin wax is receiving hot water from concentrating solar dish. This solar energy stored in PCM as latent heat energy. Solar energy stored in a day time with a large quantity, and some heat retrieved for later use. Water's temperature measured in a definite interval of time. Four cases were studied: using water as storage material with and without solar tracker. Also, PCM was as thermal storage material with and without solar tracker. The system working time was increased to about 5 h with sun tracker by concentrating dish and adding PCM to the system. The system concentrating efficiency, heating efficiency, and system productivity, has increased by about 64.07%, 112.87%, and 307.54%, respectively. The system working time increased to 3 h when PCM added without sun tracker. Also, the system concentrating efficiency increased by about 50.47%, and the system heating efficiency increased by about 41.63%. Moreover, the system productivity increased by about 180%.[14]

Manoj Kumar Sain, Godhraj Kumawat *"Performance Enhancement Of Single Slope Solar Still Using Nanoparticles Mixed Black Paint"*(2015) The present paper reports on an experiment to improve the productivity of solar still using nano-particles. Solar distillation is a relatively simple treatment of brackish or impure water. In this solar energy is used to evaporate water then this vapour is condensed as pure water. This process removes salts and other impurities. Latest trend to improve the efficiency of the solar still is use of nano-particles like metal oxides. These particles increase surface area of absorption to solar radiation. In this work the Al2O3 nanoparticles mixed black paint is used to enhance the productivity of solar still. The solar radiations are transmitted through the glass cover and captured by a black painted inner bottom surface of the solar still. Results of the study gives 38.09% increment in productivity and 12.18% increment in thermal efficiency when nano-particles of size 50 nm to 100 nm mixed black paint used at water depth .01 m. To check the significance of difference in productivity of solar still with and without nano-particle mixed black paint, a paired t-Test is performed which is conforms that the productivity enhancement due to nano-particle mixed black paint is significant at 95% confidence interval.[15]

A. Alaudeen, K. Johnson, P. Ganasundar, A. Syed Abuthahir, K. Srithar *"Study on stepped type basin in a solar still"*(July 2014) In this work a stepped solar still is used to enhance the productivity of the solar still. The concept of integrating the stepped solar still along with inclined flat plate collector is introduced in this research work. In this stepped type solar still, a conventional basin of area 1 m^2, was placed at the bottom. Experiments were conducted with various depths in the conventional basin. A conventional still was fabricated and run parallel with the experimental set up for comparison. Sensible heat storage mediums such as rocks, pebbles were added to the top basin of stepped trays and bottom conventional basins to increase the temperature of water in the still. Wicks were placed on the inclined flat plate collector to augment the evaporation rate due to capillarity. A higher evaporation rate is obtained in the packing material with wicks and pebbles in tray combinations. Theoretical analysis was performed and it agrees with experimental values. Efficiency of the system was also compared with conventional solar still.[16]

Hitesh N. Panchal & P.K. Shah ***"Investigation on performance analysis of a novel design of the vacuum tube-assisted double basin solar still: an experimental approach"*****(June 2014)** In this present work, the lower basin is connected to the conventional vacuum tubes, hence the temperature of water remains higher throughout the day and the distillate output also remains higher and always releases the latent heat of condensation to the upper basin for heating of water and enhancement of the distillate output. In this research paper, the double basin solar still with vacuum tubes fabricated was tested in climate conditions of Mehsana, (23.6000°N, 72.4000°E), Gujarat, with three different water depths 0.03, 0.04 and 0.05 m inside the lower basin and upper basin for one year time period of January 2012 to December 2012. It has been found that the double basin solar still with 0.03 m depth produced more compared with 0.04 kg and 0.05 m. It has also found that the average distillate output of the present system was found to be 8 with the monetary value of produced water being around 0.37 Rs/kg.[17]

Y.A.F. El-Samadony , A.E. Kabeel ***"Theoretical estimation of the optimum glass cover water film cooling parameters combinations of a stepped solar still"*****(2014)** In the present work, theoretical performance evaluation of a stepped solar still using water film cooling over the glass cover is investigated. The effect of film cooling thickness, flow rate, inlet temperature, and air wind speed on the stepped solar still daily productivity is studied. To increase the performance of the stepped solar still outlet water film cooling is recycled as a makeup water. It was found that film cooling thickness, volumetric flow rate, and water film inlet temperature have a significant effect on the daily distillate productivity. On the other hand, the presence of the film cooling neutralized the effect of air wind speed on the still distillate productivity. Moreover, it was found that the proper combinations of film cooling parameters have a great influence on stepped still productivity and the best combination was: film thickness from $2.5 \times 10{-}4$ to $5.5 \times 10{-}4$ m, cooling water volumetric flow rate from $4 \times 10{-}5$ to $8.5 \times 10{-}5$ m3/s, and glass cover length from 2 to 2.8 m. Finally a good agreement between the present theoretical work and previous experimental result has been obtained.[18]

Z.M. Omara , A.E. Kabeel , M.M. Younes *"Enhancing the stepped solar still performance using internal and external reflectors"*(July 2013) Studied The performance of stepped solar still with internal and external reflectors have been investigated in the current study. The reflectors are used to enhance energy input to the stepped still. The influence of internal and external (top and bottom) reflectors on the performance of the stepped solar still is investigated. A comparison between modified stepped solar still and conventional solar still is carried out to evaluate the developed desalination system performance under the same climate conditions. The results indicated that, during experimentation the productivity of the modified stepped solar still with internal and external (top and bottom) reflectors is higher than that for conventional still approximately by 125%. In this case the estimated cost of 1 l of distillate for stepped still with reflectors and conventional solar stills is approximately 0.031$ and 0.049$, respectively.[19]

Amimul Ahsan , Monzur Imteaz , Ataur Rahman , Badronnisa Yusuf , T. Fukuhara *"Design, fabrication and performance analysis of an improved solar still"*(February 2012) in this paper, a detail comparison of the design, fabrication, cost and water production analysis between an old Tubular Solar Still (TSS) and improved (new) one is presented. Since the cover material, a vinyl chloride sheet, of the old TSS was a little bit heavy, expensive and cannot be formed into a desirable size easily, a highly durable polythene film was adopted as the cover of the new TSS. The new TSS is made of cheap and locally acquisitioned lightweight materials. Consequently, the weight and cost of the new TSS were noticeably reduced and the durability was distinctly increased. A few field experiments on the new TSS were carried out in Fukui (Japan) and Muscat (Oman) and the observed results are compared with the old one. The water production flux is proportional to the temperature difference inside the still. Evaporation mass transfer coefficients (MTCs) and heat transfer coefficients (HTCs) are higher than those of condensation. Convection HTCs are much lower than those of evaporation/condensation. Finally, a linear relation is newly found between the total HTCs and MTCs.[20]

P. MonoweM. MasaleN. NijegorodovV. Vasilenko*"A portable single-basin solar still with an external reflecting booster and an outside condenser"*(October 2011)In this paper, a new design of a portable thermal–electrical solar still with an external reflecting booster and an outside condenser is proposed. The still minimises the loss of latent heat of condensation to the environment. The latent heat is accumulated in a condenser and can be used to preheat saline water for domestic purposes or to operate the still during night times. Preliminary results show that the efficiency of such still could be up to 77% if the preheated saline water is used for domestic purposes, and it could be up to 85% if preheated saline water is used to operate the still during night times and to recharge the still by the next batch of preheated water.[21]

Hitesh N Panchal, P. K. Shah *"Effect of Varying Glass cover thickness on Performance of Solar still: in a Winter Climate Conditions"*(February 2011)In this research paper, an attempt has been made to unearth the effect of different thicknesses glass cover on passive single-slope single basin solar still in winter climatic conditions of Mehsana (23°12' N, 72°30') from September, 2010 to Feb. 2011. Experiment used three identical size solar stills having three different thicknesses of glass cover of 4 mm, 8 mm and 12 mm. Here, Dunkle model is used for comparison of various heat transfer coefficients of solar stills. The objective of the present paper is to evaluate the behavioural variation in various parameters on solar still. Six month study shows that, lower glass cover thickness gives increase in distillate output, water temperature, evaporative heat transfer coefficient, convective heat transfer coefficient as well as efficiency of solar still. Hence, 4 mm glass cover thickness is most prominent thickness of present experiment.[22]

A.El-Sebaii, E.El-Bialy ***"Advanced designs of solar desalination systems"*****(January 2011)**A reviewedof thesolar still is an ideal source of fresh water for both domestic and agricultural aspects. It is one of the most important viable applications of solar energy. The simple stand most proven type of solar stills is the single basin type, but it's thermal performance is limited. Many research papers were presented where different methods were performed to improve the productivity of single basin solar stills. In this paper, a Review of different designs of solar stills was presented particularly the double, triple and multi-effect solar stills, vertical stills, tubular type solar stills, finned and corrugated stills, and stepped type solar stills. A detailed cost analysis for different configurations was presented. An optimum area of the vertical still absorber was found to be $3.5m^2$. From the results obtained for the tubular solar still it was concluded that with cooling air flow, the production increased by about 32.8%, and with cooling water flow, it further increased by about 59% more than the system without cooling. A maximum increase in productivity of about 98% was achieved for stepped solar stills when fins, sponge and pebbles were used. The maximum productivity of stepped solar still was obtained with tray depth and width of 5 and 120 mm, which is about 57.3% higher than that of the conventional still.[23]

Abdul Jabbar N. Khalifa ***"On the effect of cover tilt angle of the simple solar still on its productivity in different seasons and latitudes"*****(January 2011)** has many experimental and numerical studies have been carried out on different configurations of solar stills to optimize the design by investigating the effect of climatic, operational and design parameters on its performance. One of the main parameters that have received a considerable attention is the cover tilt angle. A large number of studies on the effect of cover tilt angle on productivity in different seasons and latitude angles are cited in this article. The investigation that tackle the detailed effect of the cover tilt angle on productivity report contradictory conclusions about the effect of tilt angle on productivity and the value of the optimum tilt angle. A relation between the cover tilt angle and productivity of simple solar still in various seasons is established together with a relation between the optimum tilt angle and the latitude angle by an extensive review of the literature. The conclusions of this study should assist in choosing the proper cover tilt angle in various seasons and latitudes.[24]

Hitesh N Panchal , P. K. Shah ***"Modelling and verification of single slope solar still using ANSYS-CFX"*****(January 2011)**Solar distillation method is an easy, small scale and cost effective technique for providing safe water. It requires an energy input as heat and the solar radiation can be source of energy. Solar still is a device which uses process of solar distillation. Here, a two phase, three dimensional model was made for evaporation as well as condensation process in solar still by using ANSYS CFX method to simulate the present model. Simulation results of solar still compared with actual experiment data of single basin solar still at climate conditions of Mehsana (23°12' N, 72°30'). There is a good agreement with experimental results and simulation results of distillate output, water temperature and heat transfer coefficients. Overall study shows the ANSYS CFX is a powerful tool for diagnostic as well as analysis of solar still.[25]

D. W. Medugu and L. G. Ndatuwong ***"Theoretical analysis of water distillation using solar still"*****(September 2009)**In developing countries, lack of safe and unreliable drinking water constitutes a major problem. To alleviate this problem, a solar still was designed and tested in Mubi, Adamawa State of Nigeria. The radiation from the sun evaporates water inside the solar still at a temperature higher than the ambient. The principle of operation is the greenhouse effect provided with the glass cover. Energy balances are made for each element of the still; solar time, direction of beam of radiation, clear sky radiation, optical properties of the cover, convection outside the still, convection and evaporation inside are accounted. Theoretical analysis of the heat and mass transfer mechanisms inside this solar still has been developed. The measured performance was then compared with results obtained by theoretical analysis. The results clearly show that the instantaneous efficiency increases with the increase of solar radiation and with the increase of feed water temperature. The distillation efficiency of the still is 99.64%as compared to the theoretical analysis.[26]

Bilal Mousa S.MohsenOmarOstaYaserElayan*"Experimental evaluation of a single-basin solar still using different absorbing materials"*(August 1998)Single-basin solar stills can be used for water desalination. Probably, they are considered the best solution for water production in remote, arid to semi-arid, small communities, where fresh water is unavailable. However, the amount of distilled water produced per unit area is somewhat low which makes the single-basin solar still unacceptable in some instances. The purpose of this paper is to study the effect of using different absorbing materials in a solar still, and thus enhance the productivity of water. Experimental results show that the productivity of distilled water was enhanced for some materials. For example, using an absorbing black rubber mat increased the daily water productivity by 38%. Using black ink increased it by 45%. Black dye was the best absorbing material used in terms of water productivity. It resulted in an enhancement of about 60%. The still used in the study was a single-basin solar still with double slopes and an effective insolation area of 3 m^2.[27]

J. W. Bloemer, J. A. Eibling, J. R. Irwin, George O. G. *"A practical basin-type solar still"*(December 1965)A basin-type solar still has been developed that is practical and economical to use in some parts of the world. Materials of construction and performance characteristics, as determined from extensive field testing and from analytical and laboratory investigations, are discussed. These studies indicate that the primary factor affecting still productivity, in addition to solar radiation, is basin depth. Of the many still designs and materials evaluated, one basic design and combination of materials appears most promising. An Office of Saline Water report giving details on the construction of such a still has been published. This paper describes that still briefly. An economic comparison of vapour-compression, flash-distillation, and basin-type solar stills shows that the solar still produces water at the lowest cost when plant capacity is below 50,000 gallons per day.[28]

Chapter 3

THEORTICAL STUDY:

Classification of Solar Still:

1) Single basin solar stills
2) Inclined solar stills
3) Multi-basin solar stills

3.1 Single Basin Solar Still

The single basin solar still represents one of the earliest designs used for distillation of water using solar energy directly. Its main advantage lies in its easy construction and simplicity of operation and maintenance. Basically, it consists of an airtight assembly enclosed at the top by a cover which is transparent to solar radiation, but opaque to the long wavelength radiation. The assembly is partially filled with the saline or brackish water. The absorption of solar radiation by the basin liner and water causes evaporation of water. The air-vapour mixture therefore attains higher temperature and lower density at the water surface. It moves upwards by the convection currents established because of the density gradient so created. When air-vapour mixture comes in contact with the top cover which is at a lower temperature as compared to the water surface, it cools down to saturation resulting in the condensation of water. The condensed water trickles down the inner surface of the top cover and is collected as distilled water in the troughs provided along lower edges of the top cover.

Single basin solar stills are again classified according to the shape of the top transparent cover

1) Single slope type
2) V type solar still
3) Inverted V type solar still
4) Hemispherical type solar still

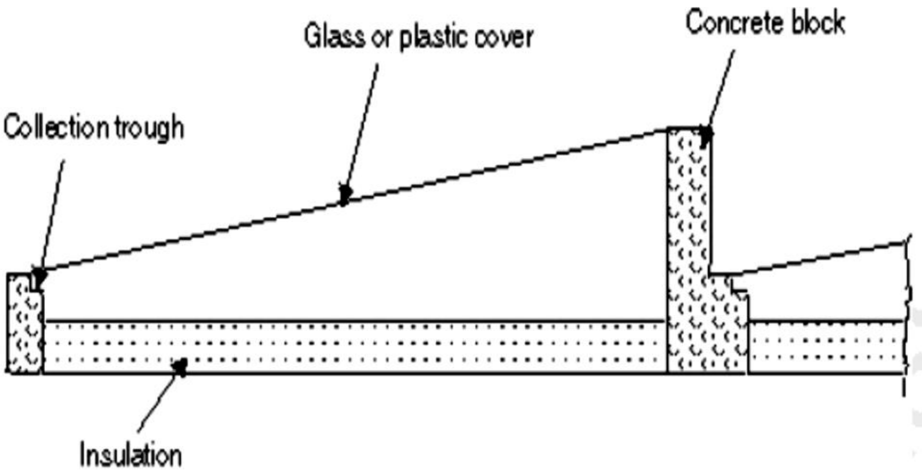


Figure 3.1.1:Single slope type solar still

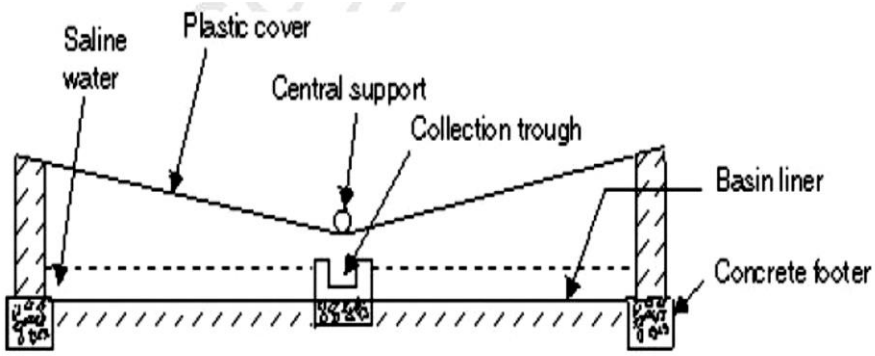


Figure 3.1.2: V type solar still

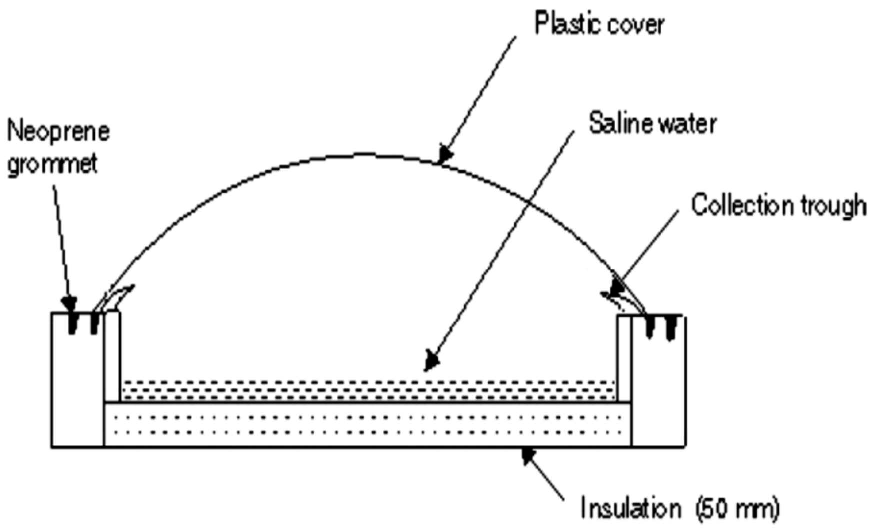


Figure 3.1.3: Hemispherical type solar still

3.2 Inclined solar stills

As the name suggest the basin of this type of still is inclined at some angle to the horizontal. By making this type of stills, the distillate output is increased. Figure 7 shows the inclined solar still.

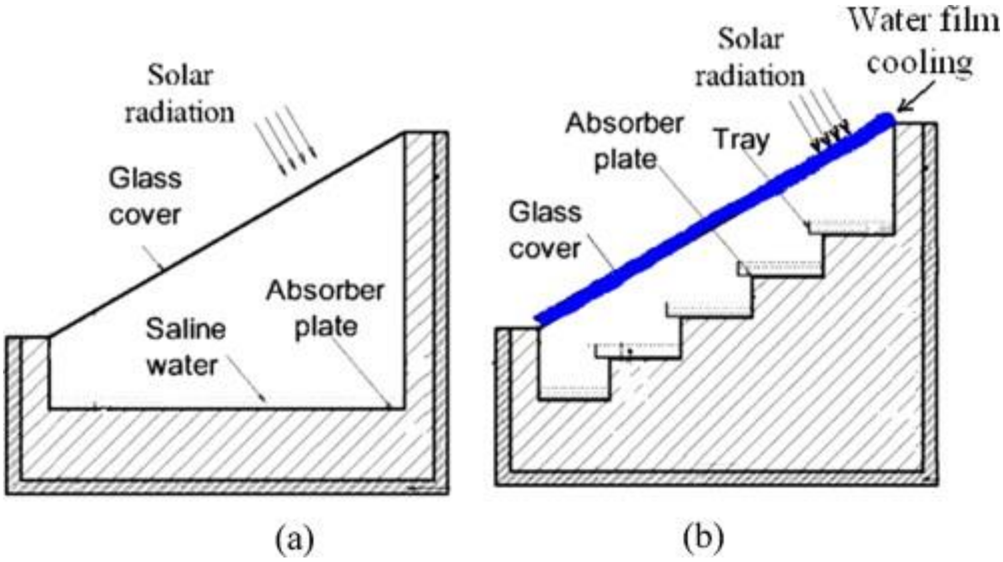


Figure 3.2: Inclined solar still

3.3 Multi-basin solar stills

In this type of solar still, the basin is divided in to more than one chamber. Both chambers is filled with brackish water.

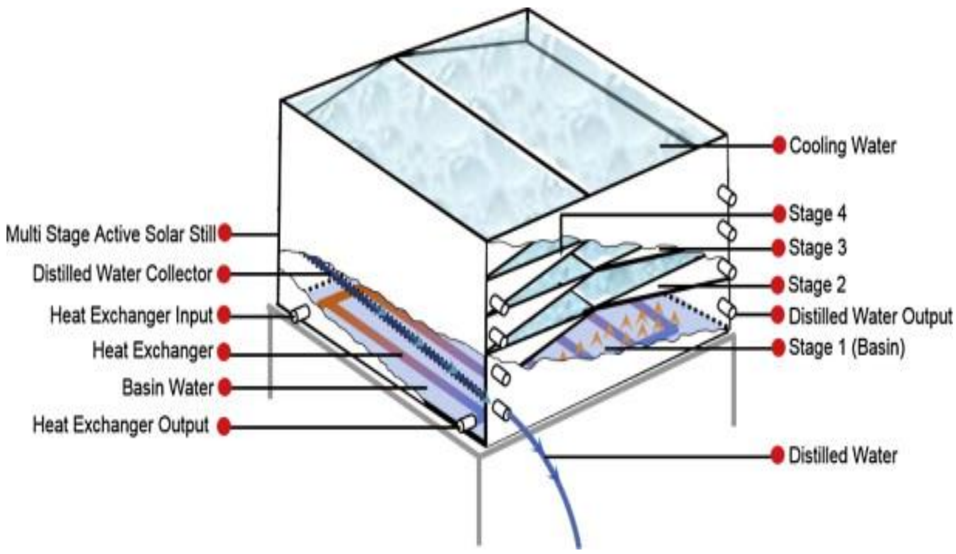


Figure 3.3: Multi basin solar still

3.4 Comparison Between Stepped and Basin Type Solar Stills:

Stepped Type Solar Still	**Basin Type Solar Still**
1) Complex design	1) Easy to design and manufacture
2) More chances of leakages than basin type	2) Less leakage loss
3) High construction and maintenance cost	3) Low initial and maintenance cost
4) Less storage capacity of water	4) More storage capacity of water
5) Thin layer of water is obtained on each step which helps in faster evaporation of water	5) Easy to relocate
6) Water vapour has to travel less distance	6) More inner area so water vapour has to travel more distance
7) Less time consuming	7) More time consuming
8) It is highly efficient	8) Less efficient
9) As the area of contact with surface is more the heat generating capacity increases	9) Less heat generating capacity due to minimum area of contact with surface

Table 3.4: Comparison Between Stepped and Basin Type Solar Stills

3.5 Dimensions of Stepped Type Solar Still:

Step Width	0.12m
Step Length	0.80m
Step Height	0.08m
Glass area	0.533m^2
Base area	0.5m^2
Glass thickness	0.006m
Glass slope	18.45^o

Table 3.5 Dimensions of Stepped Type Solar Still

3.6 Dimensions of Basin Type Solar Still:

Basin Width	0.61m
Basin Length	0.82m
Basin Height	0.42m
Glass area	$0.533m^2$
Base area	$0.5m^2$
Glass thickness	0.006m
Glass slope	18.45^o

Table 3.6: Dimensions of Basin Type Solar Still

3.7 Actual Model:

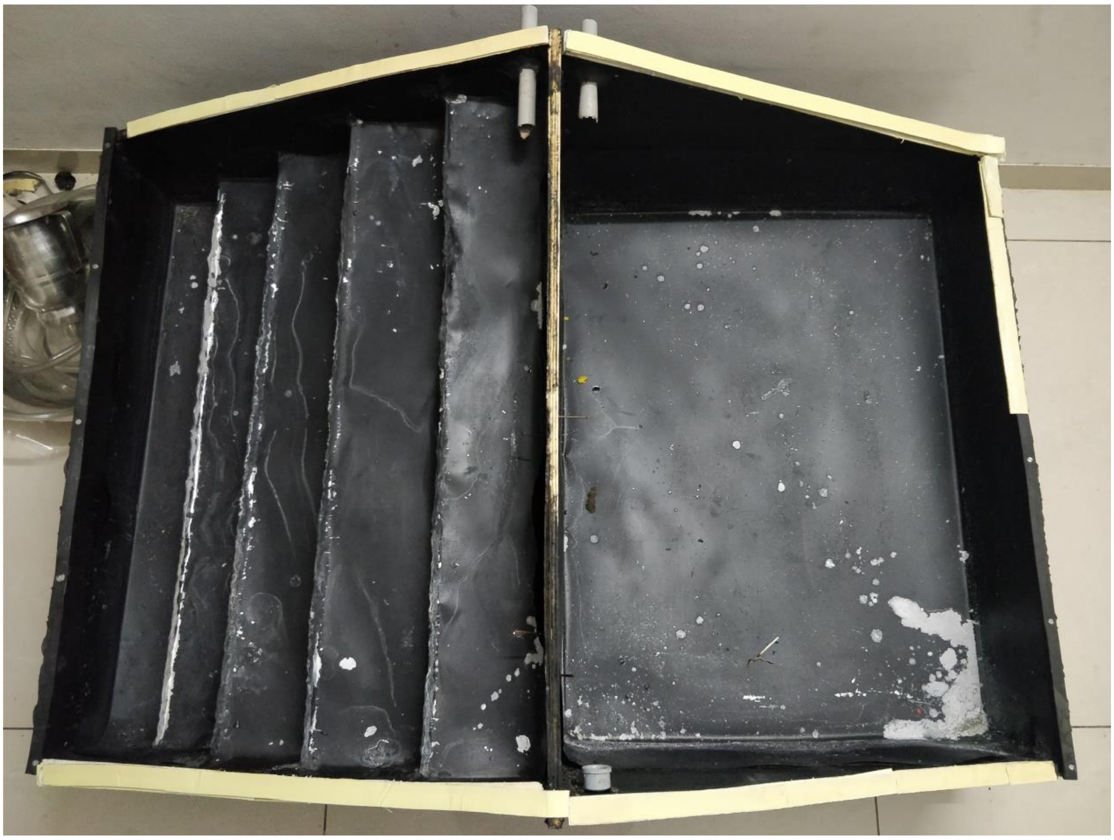


Figure 3.7: Actual Model

Chapter 4

DESIGN AND MATERIAL SELECTION:

4.1 Design objectives for an efficient solar still

For high efficiency the solar still should maintain:-

1) A high feed (un-distilled) water temperature
2) A large temperature difference between feed water and condensing surface
3) Low vapour leakage
4) A high feed water temperature can be achieved if:-
5) A high proportion of incoming radiation is absorbed by the feed water as heat. Hence low absorption glazing and a good radiation absorbing surface are required
6) Heat losses from the floor and walls are kept low
7) The water is shallow so there is not so much to heat.
8) A large temperature difference can be achieved if:-
9) The condensing surface absorbs little or none of the incoming radiation
10) Condensing water dissipates heat which must be removed rapidly from the condensing surface by, for example, a second flow of water or air, or by condensing at night.

4.2 Design Considerations

Different designs of solar still have emerged. The single effect solar still is a relatively simple device to construct and operate. However, the low productivity of the Solar still triggered the initiatives to look for ways to improve its productivity and Efficiency. These may be classified into passive and active methods.

Passive methods include the use of dye or charcoal to increase the solar absorptivity of water, applying good insulation, lowering the water depth in the basin to lower its thermal capacity, ensuring vapour tightness, using black gravel and rubber, using floating perforated black plate, and using reflective side walls.

Active methods include the use of solar collector or waste heat to heat the basin water, the use of internal] and external condensers or applying vacuum inside the solar still to enhance the evaporation/condensation processes, and cooling the glass cover to increase the temperature difference between the glass and the water in the basin and hence increases the rate of evaporation. Single-basin stills have been much studied and their behaviour is well understood. The efficiency of solar stills which are well-constructed and maintained is about 50% although typical efficiencies can be 25%. Daily output as a function of solar irradiation is greatest in the early evening when the feed water is still hot but when outside temperatures are falling. At very high air temperatures such as over 45ºC, the plate can become too warm and condensation on it can become problematic, leading to loss of efficiency.

4.3 Problems with solar stills due to design considerations

1) Poor fitting and joints, which increase colder air flow from outside into the still
2) Cracking, breakage or scratches on glass, which reduce solar transmission or let in air
3) Growth of algae and deposition of dust, bird droppings, etc. To avoid this the stills need to be cleaned regularly every few days
4) Damage over time to the blackened absorbing surface.
5) Accumulation of salt on the bottom, which needs to be removed periodically
6) The saline water in the still is too deep, or dries out. The depth needs to be maintained at around 20mm.

4.4 Design for Making a Good Solar still

The cover can be either glass or plastic. Glass is preferable to plastic because most plastic degrades in the long term due to ultra violet light from sunlight and because it is more difficult for water to condense onto it. Tempered low-iron glass is the best material to use because it is highly transparent and not easily damaged (Scharl & Harrs, 1993). However, if this is too expensive or unavailable, normal window glass can be used. This has to be 4mm think or more to reduce breakages. Plastic (such as polyethylene) can be used for short-term use. Stills with a single sloping cover with the back made from an insulating material do not suffer from a very low angle cover plate at the back reflecting sunlight and thus reducing efficiency.

It is important for greater efficiency that the water condenses on the plate as a film rather than as droplets, which tend to drop back into the saline water. For this reason the plate is set at an angle of 10 to 20º. The condensate film is then likely to run down the plate and into the run off channel. Brick, sand concrete or waterproofed concrete can be used for the basin of a long-life still if it is to be manufactured on-site, but for factory-manufactured stills, prefabricated Ferro-concrete can be used. Moulding of stills from fibre glass was tried in Botswana but in this case was more expensive than a brick still and more difficult to insulate sufficiently, but has the advantage of the stills being transportable.

By placing a fan in the still it is possible to increase evaporation rates. However, the increase is not large and there is also the extra cost and complication of including and powering a fan in what is essentially quite a simple piece of equipment. Fan assisted solar desalination would only really be useful if a particular level of output is needed but the area occupied by the stills is restricted, as fan assistance can enable the area occupied by a still to be reduced for a given output.

Sufficient Insulations of wool, Thermocol, sealants etc. are provided inside the Basin in order to prevent loss of heat.

4.5 Material Used for Construction:

4.5.1 Material Used

1) The side and bottom walls need to be insulated. This can be achieved by using multi-layered insulator. Glass wool will be sand-witched between two metallic plates.
2) The main frame is composed of steel owing to its corrosion resistance, low weight, long life and easy clean ability.
3) The outside of the complete distiller is coated with carbon black to increase absorption of radiation.
4) The cover on the top is made of tempered glass so that the birds can't see their reflection and hence avoid nuisance.

4.5.2 Properties of Material

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

1) Materials should have a long life under exposed conditions or be inexpensive enoughto be replaced upon degradation.
2) They should be sturdy enough to resist wind damage and slight earth movements.
3) They should be nontoxic and not emit vapours or instill an unpleasant taste to the water under elevated temperatures.
4) They should be able to resist corrosion from saline water and distilled water.
5) They should be of a size and weight that can be conveniently packaged, and carried by local transportation.
6) They should be easy to handle in the field.

4.6 Factors Affecting productivity of solar still

4.6.1 Glass Water Temperature Difference

Increasing the difference in temperature between the glass cover and the basin water leads to an increase in the natural circulation of the air mass inside the solar still. It increases both evaporative and convective heat transfer from basin water to glass cover. The difference in temperature between the glass cover and water is considered as the driving force of the condensation process. Increasing the temperature difference between the glass cover and water can be achieved by using regenerative solar still ,still with double glasses and triple-basin still .

4.6.2 Free surface area and deepness of water

The water evaporation rate in the solar still is directly proportional to the exposure water area. As a result, increasing the free surface area of the water in the basin improves the solar still production. For achieving this, sponge is used at the basin water. The basin water deepness strongly influences the basin yield, as the water deepness is inversely proportional to the still productivity. It has been found that for the least water deepness, the productivity has reached maximum. If minimum deepness in the solar still is maintained constant, dry spot will occur. For this reason maintaining minimum deepness in the solar still is considered very difficult. Wick type solar stills, stepped solar still and a plastic water purifier were developed. The effect of different deepness of water in the solar still was established by Khalifa and Hamood. Extreme operating condition in shallow solar stills was reported by Porta et al.

4.6.3 Inlet water temperature

The saline water temperature controls the evaporation rate as the latter increases with the increase of the temperature of the unpurified water. Parabolic concentrators, plate collector, mini solar pond are combined with the solar still to increase its temperature. Large amounts of energy may be needed for increasing the temperature of the entire solar still water. The evaporation rate is directly proportional with the temperature of the water free surface area. Therefore, we can use baffle suspended absorber plates to increase the water free surface area . The amount of condensed water is significantly dependent on the temperature difference between the glass cover and the water in the still and on their individual temperatures. Also increasing the difference in temperature between the glass cover and the brine causes an increase in the productivity. When the temperature difference increased from 6 °C to 11 °C, the productivity increased from 0.1 kg/m2/h to reach a value of 0.85 kg/m2/h. At the same temperature difference of 10 °C, a productivity of 0.8 kg/m2/h was obtained when the brine temperature was 70 °C, whereas the productivity reduced to reach a value of 0.1 kg/m2/h when the brine temperature became 30 °C.

4.6.4 Angle, thickness and material for glass cover

Singh and Tiwari reported that the annual solar still yield reached a maximum value when the condensing glass cover inclination was equal to the latitude of the place. In India, Kumaretal conducted a similar study at (latitude 28.36°N). Based on their numerical analysis, better performance could be made from a glass slope angle of 15°. Akash et al. found that a 35° glass inclination angle led to a maximum yield in the month of May. In Jordan, Khalifa and Hamood conducted experiments at (latitude 31.57°N) and investigated the effect of tilting cover on basin solar stills performance. It was found that tilting the covers alone could change the output by almost 63%. The heat transfer through the glass cover improved when its thickness decreased and the thermal conductivity increased. Experimental results showed that solar still yield enhanced by 16.5% with cover of 3 mm glass thickness than that of 6mm glass thickness. Material selection for solar stills is very significant; the cover material may be made of either plastic or glass.

Glass is the preferred because of its greater solar transmittance for different angles of incidence and its long-term use, whereas a plastic (such as polyethylene) can be used for short-term use.

4.6.5 Techniques used to improve the performance of the solar still

Many meteorological parameters and design, operational have an effect on the performance of the solar still such as the use of sponge cubes and wicks, vacuum technique by external and internal condenser, combined solar still, internal and external reflector, conventional solar still connected with solar collector and phase change material incorporated with solar stills, modified stepped solar still and conventional solar still with nanoparticles.

4.6.6 Sponges cubes and gravels

Murugavel et al. evaluated the performance of the solar still with various spreader materials such as jute cloth, cotton cloth, a sponge sheet and porous materials such as quartzite rock and natural rock. The results confirmed that the use of the black light cotton cloth gave the most productivity. The temporary performance of an active single basin solar still inserted with a thin layer of a sensible storage material under the basin liner of the still in order to produce fresh water during the night-time was shown by. Sand is inexpensive and available so it is the best choice to be used as a storage material. From the results, the addition of 10 kg sand as storage material enhanced the daily productivity to reach a value of almost 4.005 (L/m2/day) with a daily efficiency of about 37.8%. When sand was not used, the daily productivity reduced to a level of 2.852 L/m2/day with a daily efficiency of 27%. The annual average daily yield of the still with storage has been found to be 23.8% greater than that without storage. The influence of black gravel on the productivity of the solar still was studied by Nafey et al. The solar still with gravel is shown in Fig. 31. Productivity has been enhanced by 19% by using of gravels.

4.6.7 Phase change materials

The principle of latent heat storage depends mainly on the fact that the material changes its phase when it is exposed to heat. As an example, the material changes from liquid to vapour by storing the heat as latent heat of vaporization or it changes from solid to liquid as latent heat of fusion. According to Fath, the latent heat thermal energy storage systems have numerous features over sensible heat storage systems like the steady temperature for charging and discharging and the huge energy storage capacity per unit volume. Radhwan stated a study of a temporary performance of a steeped solar still with compact latent heat thermal energy storage for the purpose of warming and humidifying of agricultural greenhouses (GH). In addition, he discussed the influence of paraffin wax thickness as a PCM and the influence of mass flow rate of air on the system performance. His results showed that minimizing the air flow rate had a considerable effect on the still yield, but the green house heat load decreased.Aluminium turnings were added to an emulsion that consisted of paraffin wax, paraffin oil and water to enhance heat conduction then, save heat during the daytime and finally liberate it at night. The former mixture used as a special phase change material. It improved the productivity to a maximum value of nearly 851 mL/m2h when the supply of saline water was 40 mL/min.

4.6.8 Solar Distillation

Solar distillation has been used for many years, usually for comparatively small plant outputs. Over the years, substantial research has been carried out to find out ways into improving the efficiency of the process. Research work has been carried out in many parts of the world.

Solar distillation uses, in common with all distillation processes, the evaporation and condensation modes, but unlike other processes energy consumption is not a recurrent cost but is incorporated in the capital cost of the solar collector. The solar still therefore, is of a simple design, construction and maintenance with ease of operation. It is best suitable for regions of the world with high solar intensities.

The mechanism of operation is based on the transmitting, absorption and reflective properties of glass and other transparent materials. The glass has the property of transmitting incident short-wave solar radiation which passes through the glass, the glass being a medium of transfer of heat, into the still to heat the brine.

However, the re-radiated wavelengths from the heated water surface are infra-red and very little of it is transmitted back through the glass as it is shown in Figure 3.1.

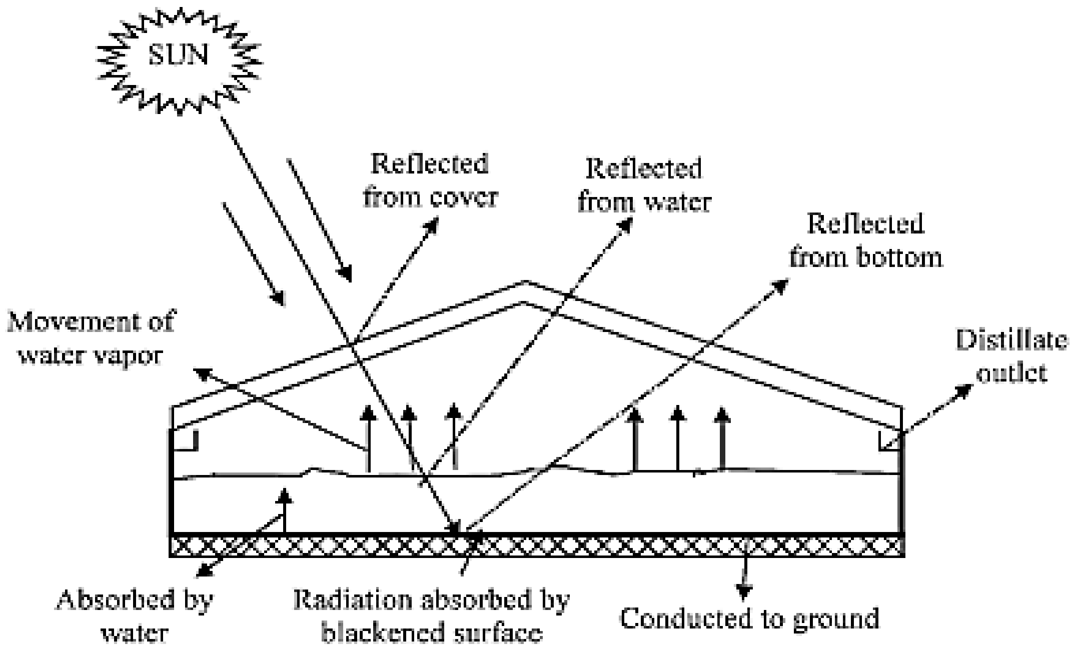


Figure 4.6.8.1: Schematic diagram of a basin-type solar still

Today, producing volumes of pure potable water is not only technically feasible but equally economically viable using the desalination of seawater. The challenge though has been to produce potable water for rural communities for drinking and sanitation to help meet the Millennium Development Goal without compromising standards.

In meeting the challenges of the provision of potable water for drinking and sanitation, huge desalination plants have been built. The introduction of dual-power plants were also deployed to reduce the cost of electricity and water which could impact negatively on the populace. Exhaust heat from power plants were also deployed as an alternative for running desalination systems. These are large desalination systems though. However, not all water demands are coupled with the need for additional electric power.

Solar energy may be deployed to produce fresh water from the sea. This may be accomplished in a large system or in a simple basin-type solar desalination unit.

On a practical basis, certain things ought to be taken into consideration while designing and operating a solar still. For instance, shallow basins require large expanse of land. This land has to be cleared and levelled in readiness for the installation of the still; obviously this attracts some additional cost. Oftentimes and because the water to be treated is salt water, salt crystals build up on the dry part of the basins. This can reduce the overall absorption area of the basin, thereby impacting negatively on the effective basin area. Leakage can cause distillate to leak back into the basin or even leak out of the basin. It is equally necessary to flush the still basin on a regular basis so as to remove accumulated salts and microbes that might have grown in the brines. The use of algaecides might also be encouraged to control the growth of algae.

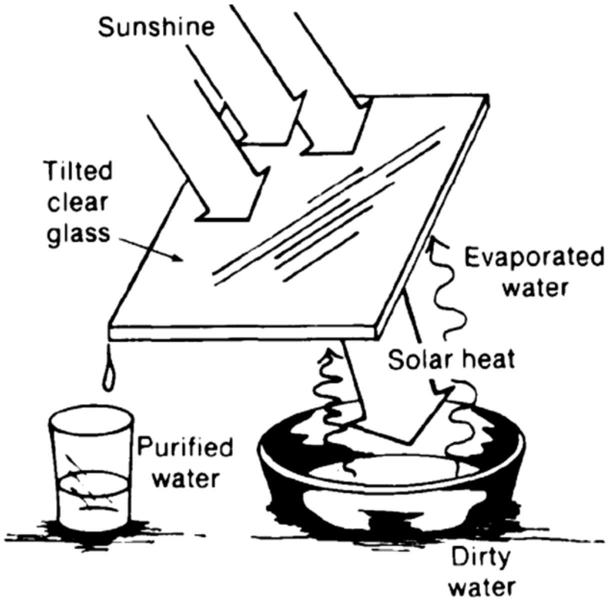


Figure 4.6.8.2: Basic concept of solar distillation

4.6.9 Basin-Type Solar Still Design

Certain factors influence the choice or selection of different Renewable Energy Sources for any given desalination technology. Since the primary focus is the world's poorest countries believed to be in the tropics, the most viable renewable source would be the solar energy. However, the most important considerations should be the simplicity of the design, its affordability, sustainability, and maintainability and operational ability.

The basin-type solar still is an artificial way of replicating the hydrological cycle. The stills apply the principles of evaporation and condensation that is seen within the precipitation cycle. Stills can however, be classified into two main categories; active and passive. Active stills often employ mechanical methods to replenish the water supply; these stills require more maintenance, skilled labour and an energy input. For these reasons the active basin solar stills are not regarded as an economical option for providing potable water, especially in developing countries.

There are a few concepts that are generally applied to the conventional still design.

The glass must be at a minimum of 100 to the horizontal to allow the condensate to flow effectively into the collecting tube; yet still allow as much solar energy to reach the water as possible. The angle of the glass should be increased for different latitudes to obtain the optimum angle. It is also important to note that the positioning of the solar still in terms of North and South will change with the hemisphere. The basin is often painted black to absorb a greater amount of radiant heat; the most suitable application would be a coat of matt black paint to ensure that very little is reflected.

Despite the fact that solar stills are easily constructed and employ principles that have been known for centuries there are major inefficiencies within the system. The conventional still suffers from: low water yield due to the combination of condensation and evaporation in one chamber; microbial contamination when subjected to long periods of low temperatures; shallow basin stills store small amounts of sensible heat and it relies on human factors to maintain optimum performance. The success of the still relies on the replenishment of water; and maintenance routines such as the flushing of the basin to remove microbial build-up and clearing dust particles and dirt from the glass surface. These factors all contribute to the average efficiency of the still.

There has been extensive research on the adaptations that can be made to the conventional still design to improve the performance of the system. These investigations have included structural changes such as baffle plates, reflective back plates, wick methods; physical methods such as evacuation; use of coupling of a flat plate; storage methods by use of dye or sensible heat storage; the performance of a single slope basin still with some computational model; development of active passive still with separate condenser; and the use of phase change materials (PCM) .These methods are all an attempt to improve the water yield over the 24 hour period; however the more adaptations that are made the more expensive the still becomes. A simple, cheap but effective solution must be found.

The biggest contributing factor to the effectiveness of the conventional still is the temperature difference between the basin and the glass – the larger the temperature difference the greater the condensation rate. Shallow basin stills are more productive than deep basin stills overall, however during the night the water cools rapidly as little sensible heat is stored within the water.

Adaptations such as incorporating a sun tracking system which can be used with single-axis solar concentrating systems as an enhancer have been attempted to improve the performance of the still. The key objective of this project therefore, is to improve the performance of a traditional single slope solar still through the combined functioning of the solar still with a sun tracking mechanism to increase the solar still capability to capture more solar radiations which in turn would increase distillate yield.

Figure 4.6.9: Basin-type Solar Stills having varying Angles of Inclination

4.6.10 Stepped Type Solar Still

Solar still is widely used in solar desalination processes. But the productivity of the solar still is very low. To enhance the productivity of the single basin solar still many research works is being carried out up till now. The various factors affecting the productivity of solar still are solar intensity, wind velocity, ambient temperature, water–glass temperature difference, free surface area of water, absorber plate area, temperature of inlet water, glass angle and depth of water. The solar intensity, wind velocity, ambient temperature cannot be controlled, as they are metrological parameters. Whereas, the remaining parameters can be varied to enhance the productivity of the solar stills. Depth of water in the solar still inversely affects the productivity of the solar still. Maintaining minimum depth in the solar still is very difficult.

For maintaining minimum depth, wicks, plastic water purifier and stepped solar still were used. Investigations indicated that a reduction of the brine depth in the still improves the productivity, mainly due to the higher basin temperature. So that stepped solar stills can increase the distillate productivity about conventional solar stills, many reports studied the performance of stepped solar still. In this review, we are attempting to study the present status of different designs of stepped solar stills.

For improving the evaporation rate, a stepped tray type basin along with an inclined flat plate collector and a conventional basin is constructed. The water collection areas were improved by connecting the stepped trays of 12 number. Different water depths of 2 cm, 3 cm, 4 cm were used in the conventional basin while a constant 2 cm water depth was maintained in the stepped tray type basin. Maximum productivity of 1468 kg/ cm2 was obtained for 2 cm water depth and lowest production of 1150 kg/m2 is obtained for 4 cm water depth.

Sponges are added to improve the capillary action. For 2 cm water depth with wick and sponge combination the maximum output of 1305 kg/m2 was obtained. The lowest productivity was recorded for 4 cm water depth with sponges combination (1280 kg/m2). Different packing materials such as wooden chips, sand, coal, coconut coir, were added in the inclined flat plate collector to increase the area of exposure. For different packing material analysed, rock, sponge and wick combination gains the maximum productivity of 1745 kg/m2 and lowest productivity is for sand and wick combination (1200 kg/m2).

The daily efficiency of various combinations was calculated: of them coconut coir and wick combination produced 16.36%, nearly 3% increase in efficiency when compared to conventional still. Theoretical analysis was also performed and compared with experimental results. A maximum deviation of less than 10% between theoretical and experimental analysis was obtained. Cost analysis was also performed for this still, and a payback period of 320 days is required for this still which is 80 days less than that of the conventional still.

4.6.11 Heat Transfer Mechanisms in a Solar Still

The mechanisms of heat transfer within a solar still are basically dependent on the climatic effects and the amount of solar radiation that enters the basin. More importantly and frankly too, the performance of the still depends on how much of the solar irradiance that reaches the water in the basin of the solar still.

When the sun’s radiation reaches the Earth it is both scattered and absorbed by the atmosphere. The radiation that then travels through the Earth’s atmosphere is known as “sky” radiation, this is the radiation incident on the Earth’s surface after the initial waves from the sun have been absorbed and scattered by the atmosphere .The “sky” radiation that travels to the Earth’s surface can then be used as a valuable energy source for desalination.

The direct and diffuse radiation enters the still through the glass cover after partially being reflected and absorbed by the glass itself. Once in the evaporating chamber the radiation is further transmitted, reflected and absorbed by the water until it reaches the blackened basin where most of it is fully absorbed. The basin then begins to heat up and in turn through convective processes heats the water causing it to evaporate.

Due to the fact that the glass cover remains at a temperature lower than the dew point temperature (the temperature at which water saturates) the vapour begins to condense on the inside of the glass surface through the mechanism of drop-wise condensation. This is where the vapour condenses in discrete droplets and grows by means of some form of accumulation until it becomes large enough to move under gravity down the glass and can be collected in a pipe at the lower end of the still. This method of condensation has a heat transfer rate of 10 times that of film condensation which allows the heat to be dissipated at a faster rate. This allows the excess heat absorbed by the glass to be dissipated and is lost to the atmosphere.

A simple representation of the heat transfer mechanisms within a still can be seen in Figure. Often the formation of drop-wise condensation can reduce the amount of radiation entering the still, and can contribute to a reduction in distillate production in the latter part of the day.

The heat received by the film of condensed water, by radiation from the brine surface, by convection from air-vapour, and by conduction of vapour is conducted through the water film and glass to the external surface of the cover. The small amount of solar energy absorbed in the cover is also conducted outward. The heat which the cover (glass) has received is then transferred from the outer surface to the atmosphere by convection and radiation.

The heat transfer processes in the solar still are all dependent on the difference in temperature between the brine surface and the glass. The higher the difference, the greater is the energy transfer rate by each mechanism. Furthermore, the higher the brine temperature, the greater the proportion of energy usefully transferred by evaporation.

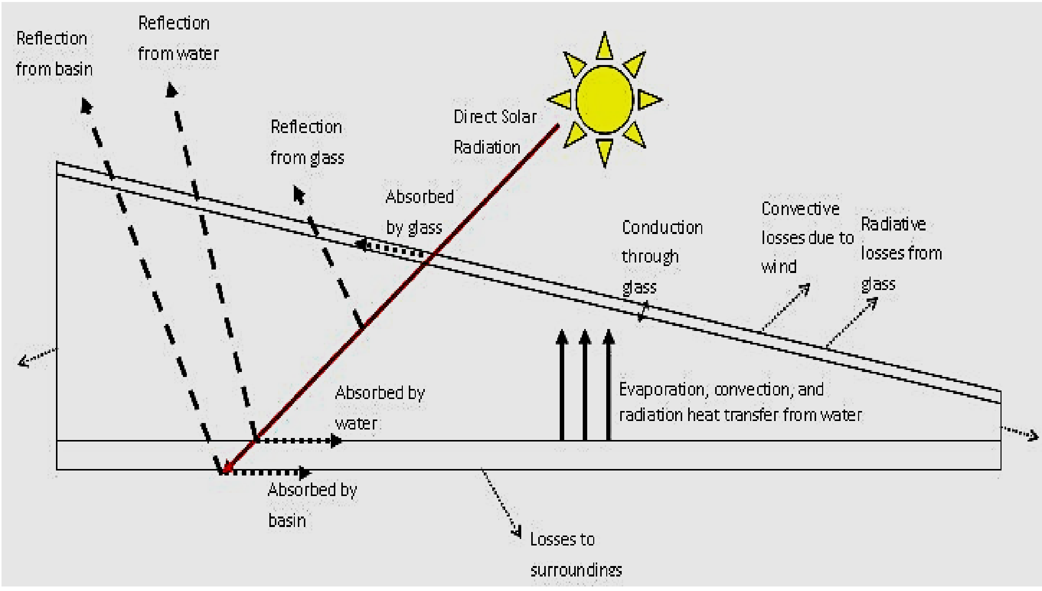


Figure 4.6.11: Heat transfer in a Basin-type Solar Still

The solar energy transmitted by the glass is partly absorbed in the brine, with the majority of it being absorbed on the basin base. Heat is conducted from the basin base surface into the brine, thereby increasing its temperature and vapour pressure; partial vaporization then occurs. The warm vapour saturated air is carried by the convection currents to the transparent glass cover, which is generally cooler than the brine. Moisture condenses on the underneath of the glass, the heat of condensation being conducted through the glass cover to the surrounding atmosphere; the partly dehumidified air drifts back to the surface of the brine for further moisture addition. A thin film of condensate flows down the transparent glass cover to the collecting trough, from which it passes to storage.

The incoming solar radiation, usually composed of direct radiation from the sun and diffuse radiation from the clouds and sky, is partly reflected by the outer and inner cover surfaces, very slightly absorbed in the cover, slightly reflected by the brine and the base of the basin; the balance is absorbed by the brine and the bottom of the basin. Another small portion of energy is lost by conduction through the bottom into the ground or through insulation under the base from the energy absorbed by the basin bottom.

The brine is warmed by the convection currents in the shallow basin to the air-water interface, where transfer of mass and energy takes place. Since the vapour pressure of the surface water is greater than the partial pressure in the air space, evaporation into the overlying air film occurs. This transfer of water is accompanied by sensible heat transfer from the warm brine into the air-vapour mixture in contact with it. Both processes produced a temperature rise and density decreased in the air-vapour mixture, causing it to rise toward the transparent glass cover.

Supplementary to the convective heat transfer from brine surface, is a transfer of heat to the cover by radiation. The glass cover is cooler than the brine partly due to the breeze from the outer side and partly due to the condensate on the inner underside, so the radiant transfer process is essentially between two water surfaces, net radiation being from the brine in the direction of the glass cover. Since the glass cover is cooler than the air-vapour mixture coming in contact with it, the difference in vapour pressure causes diffusion of water vapour through the air film to the water layer on the underside of the cover. Condensation occurs due to the latent heat being released from the water film.

Chapter 5

EXPERIMENTAL ANALYSIS AND TESTING:

5.1 Theoretical analysis for solar still

The theoretical analysis is performed using the energy balance mode on various components of the still system. To simplify the analysis, the following assumptions are made:

1) There is no vapour leakage in the still, and this is important to increase the productivity and efficiency.
2) There is no temperature gradient along the glass cover thickness and in water depth. Also the absorbed energy by the glass cover is negligible.
3) The condensation that occurs at the glass cover is a film – type.
4) When conducting energy balance in terms of (W/m2) for active still, the following assumptions are taken into consideration :
5) An optimum Inclination of the glass cover
6) The heat capacity of the glass cover, the absorbing material and the Insulation (bottom and sides) are negligible.
7) Performance is steady state.
8) Construction is of sheet and parallel tube type.
9) The headers cover a small area of collector and can be neglected.
10) The headers provide uniform flow to tubes.
11) Heat flow through a cover is one dimensional.
12) There is a negligible temperature drop through a cover.
13) There is one-dimensional heat flow through back insulation.
14) Temperature gradients around tubes can be neglected.
15) The temperature gradients in the direction of flow and between the tubes can be treated independently.
16) Dust and dirt on the collector are negligible.
17) Shading of the collector absorber plate is negligible.

The objective of this research is to study the theoretical performance of a passive solar still that is augmented by a conventional type collector. In solar distillation systems, the heat transfer can be classified in terms of external and internal heat transfer. The external heat transfer are mainly governed by conduction, convection and radiation processes, which are independent of each other, these are, the heat of the glass cover and the bottom and sides insulation. Heat transfer within the solar still is referred to as internal heat transfer who mainly consists of radiation, convection and Evaporation.

External heat transfer covers exchanges between the outside of the solar still and the surrounding for example heat transfer from the glass to the ambient, and the heat transfer from water that exist in the basin to the ambient. The theoretical model analysis can be made by dividing the heat transfer process that occurs on the still into two types, External and Internal heat transfer.

5.2 Internal heat transfer.

Internal heat transfer is that occur between water surface and the glass cover [10]. There are three methods of heat transfer from water surface to the glass cover, radiation, convection and evaporation and hence these heat transfer methods are discussed separately.

5.3 Radiation loss coefficient.

Between any two bodies there are differences in temperature, and then there are a radiation heat transfer will occur between them. In this case, the water surface and glass cover are considered as infinite parallel planes.

5.4 Observation Results:

5.4.1 Basin Type:

1) Without PCM

Reading No.	Time (Hrs)	Atmospheric Temp(^{o}c)	Temp. of Basin water(^{o}C)	Mass of Water (ml)
1	08:00	20	22	0
2	09:00	25	27	7
3	10:00	28	29	19
4	11:00	30	35	27
5	12:00	33	42	45
6	13:00	37	51	63
7	14:00	39	62	71
8	15:00	38	57	59
9	16:00	36	45	43
10	17:00	35	42	28
11	18:00	32	38	13
12	19:00	30	33	4

Table 5.4.1.1: Result Without PCM (Basin Type)

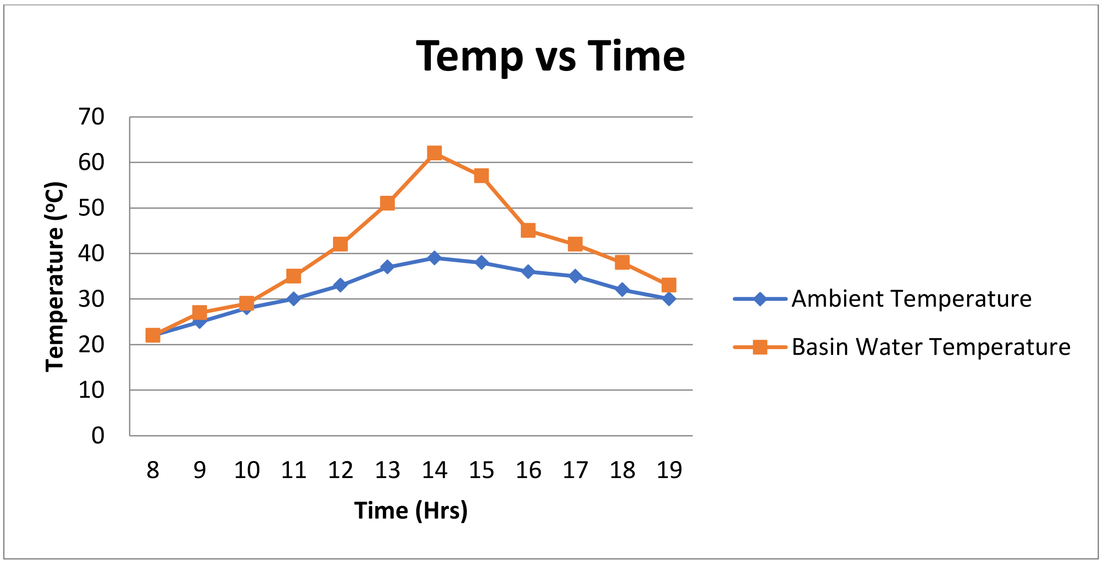


Chart 5.4.1.1: Result Without PCM (Basin Type)

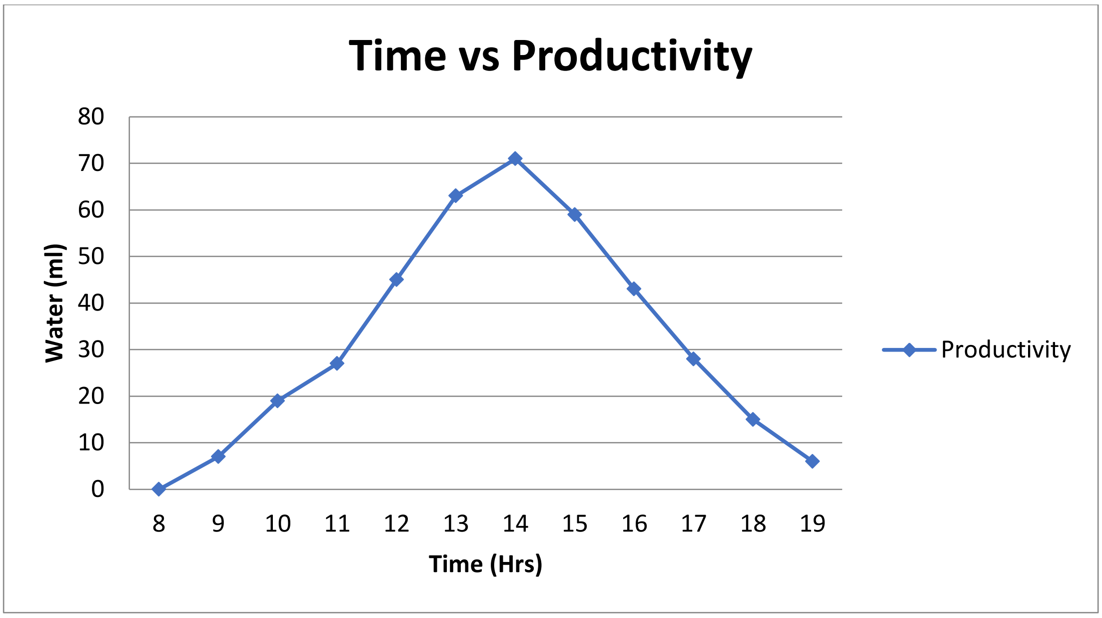


Chart 5.4.1.2 Result Without PCM (Basin Type)

Remark:

1) The maximum Basin Water Temp was 62 ^{o}C.
2) Maximum Productivity was 71 ml at 14 Hrs.

2) With PCM (Paraffin Wax):

Reading No.	Time (Hrs)	Atmospheric Temperature (^{o}c)	Temp. of Basin water (^{o}C)	Mass of Water (ml)
1	08:00	21	25	3
2	09:00	24	27	10
3	10:00	28	37	24
4	11:00	31	45	50
5	12:00	33	54	69
6	13:00	37	67	77
7	14:00	39	74	63
8	15:00	37	69	49
9	16:00	36	51	35
10	17:00	35	46	20
11	18:00	32	43	16
12	19:00	31	41	7

Table 5.4.1.2: Result With PCM (Paraffin Wax) (Basin Type)

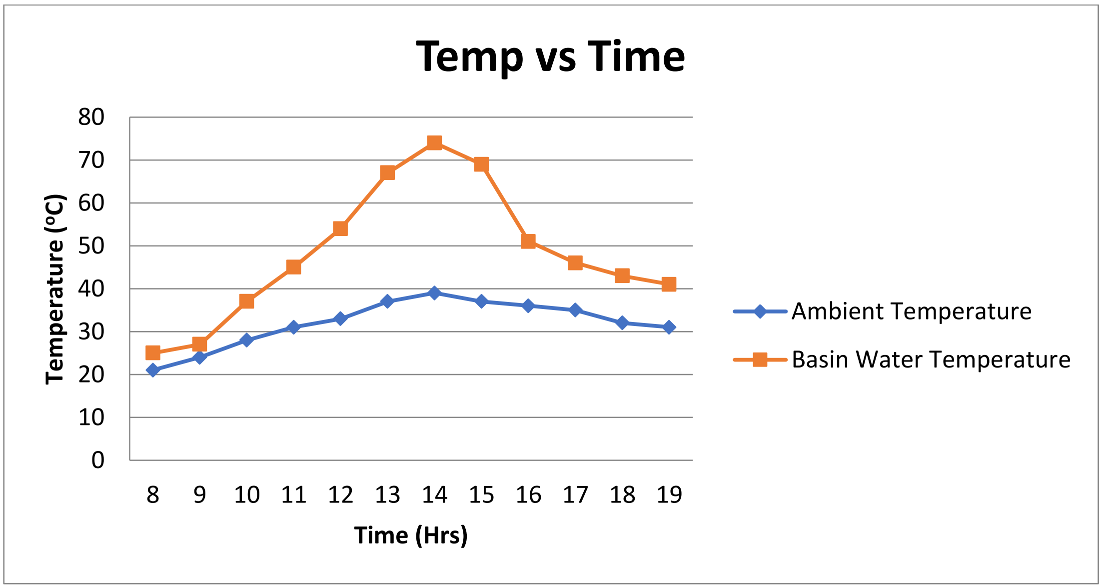


Chart 5.4.1.3: Result With PCM (Basin Type)

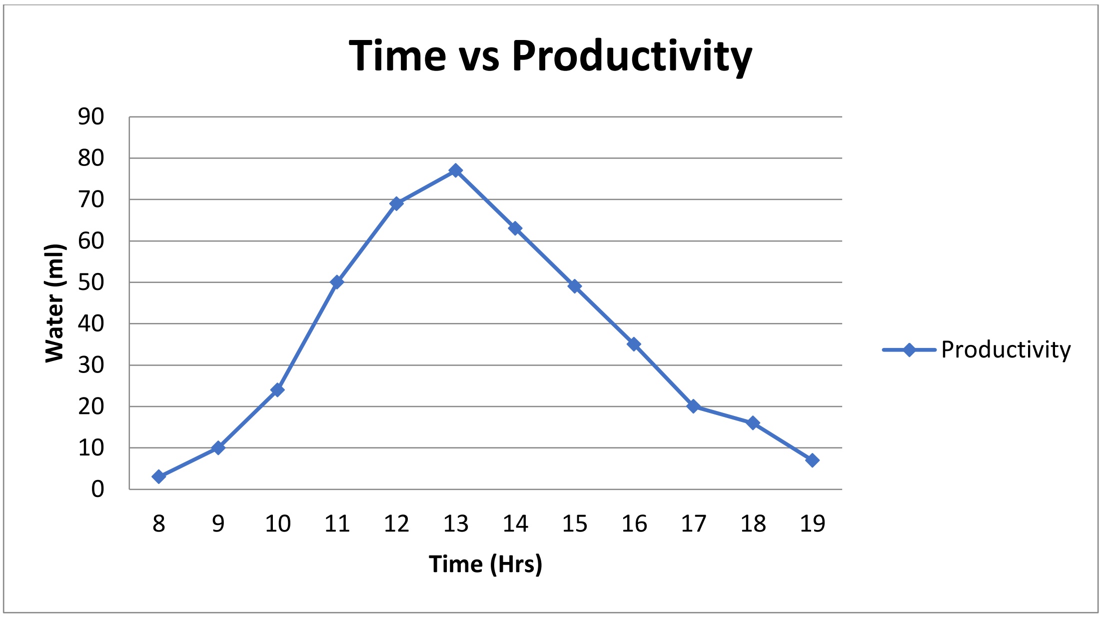


Chart 5.4.1.4: Result With PCM (Basin Type)

Remark:

1) The maximum Basin Water Temp was 74 ^{o}C.
2) Maximum Productivity was 77 ml at 13 Hrs.

5.4.2 Stepped Type

1) Without PCM:

Reading No.	Time (Hrs)	Atmospheric Temp (^{o}c)	Temp. of Basin water (^{o}C)	Mass of Water (ml)
1	08:00	20	23	0
2	09:00	25	28	15
3	10:00	28	35	25
4	11:00	30	44	37
5	12:00	33	52	65
6	13:00	37	64	78
7	14:00	39	72	87
8	15:00	38	69	82
9	16:00	36	61	63
10	17:00	35	57	45
11	18:00	32	51	23
12	19:00	30	47	8

Table 5.4.2.1: Result Without PCM (Stepped Type)

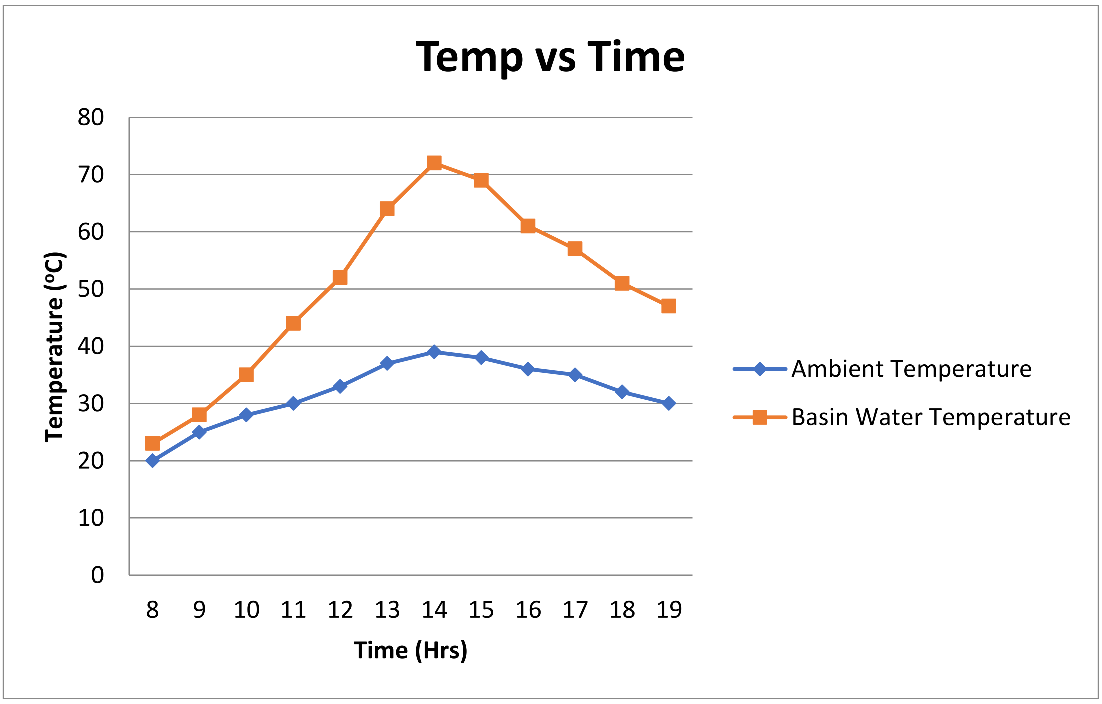


Chart 5.4.2.1: Result Without PCM (Stepped Type)

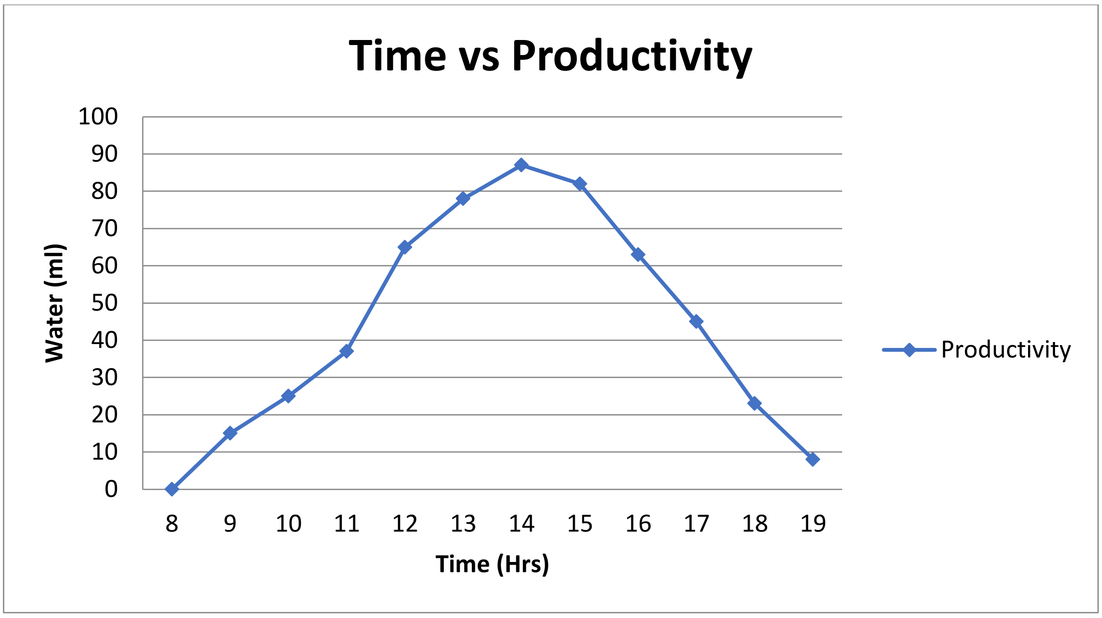


Chart 5.4.2.2: Result Without PCM (Stepped Type)

Remark:

1) The maximum Basin Water Temp was 72 ^{o}C.
2) Maximum Productivity was 87 ml at 14 Hrs.

2) With PCM (Paraffin Wax):

Reading No.	Time (Hrs)	Atmospheric Temp (^{o}c)	Temp. of Basin water(^{o}C)	Mass of Water (ml)
1	08:00	21	28	5
2	09:00	24	37	28
3	10:00	28	46	45
4	11:00	31	57	66
5	12:00	33	69	92
6	13:00	37	78	105
7	14:00	39	84	120
8	15:00	37	77	98
9	16:00	36	64	79
10	17:00	35	59	61
11	18:00	32	55	39
12	19:00	31	49	14

Table 5.4.2.2: Result With PCM (Paraffin Wax) (Stepped Type)

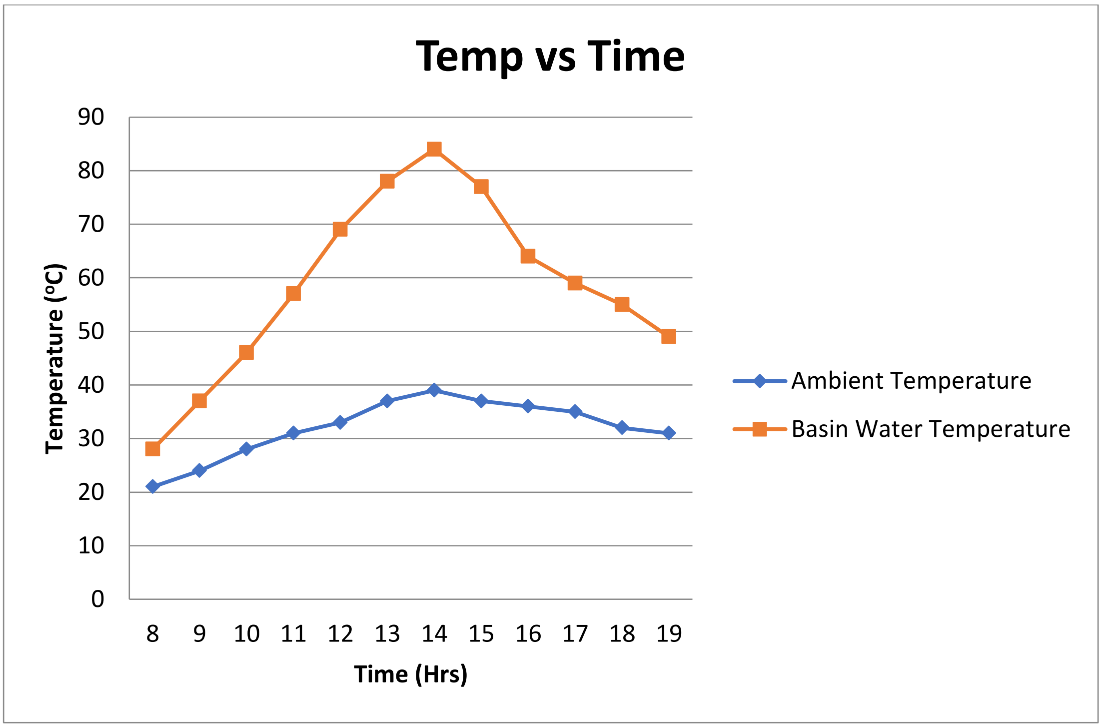


Chart 5.4.2.3: Result With PCM (Stepped Type)

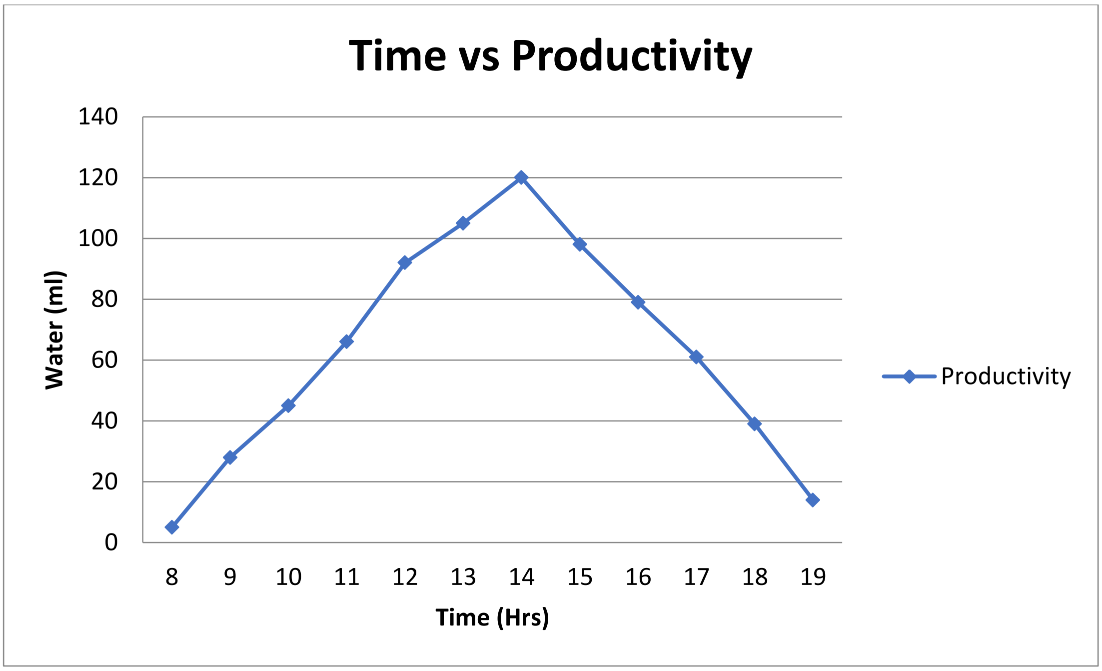


Chart 5.4.2.4: Result With PCM (Stepped Type)

Remark:

1) The maximum Basin Water Temp was 84 ^{o}C.
2) Maximum Productivity was 130 ml at 14 Hrs.

Chapter 6

COST ESTIMATION:

Sr. No.	Material Name	Specification	Cost (Rs.)
1	Cost of Wooden box	Area of 4 m^2 cuts into 6 pieces.	2500
2	Cost of Insulating Material (Thermocol)	Thermocol, since it is least expensive & has light weight.	400
3	Cost of G.I. Sheet	Area of 3 m^2. Increases heat transfer of water.	750
4	Cost of paint	3 spray paints.	190
5	Cost of PCM	Parrafin wax. Since it helps in absorbing heat.	1500
6	Cost of pipes and fittings	Steel pipe of Diameter of 2.5 cm.	1000
7	Cost of Solar Panel	To Convert solar energy into electrical energy.	1000
8	Cost of water Pump	To re-circulate saline water.	600
9	Cost of cover glass	To collect water droplets.	600
10	Cost of Over head tank	10 litre capacity. To provide water to model.	650
11	Cost of Temp. Sensors	Digital thermometer. To measure inside temp.	900
12	Net cost of Project	Total cost of model	11290

Table 6.1 Cost Estimation

Chapter 7

CONCLUSION & FUTURE SCOPE

7.1 Conclusion:

Distillation is a method where water is removed from the contaminations rather than to remove contaminants from the water. Solar energy is a promising source to achieve this. This is due to various advantages involved in solar distillation. The solar distillation involves zero maintenance cost and no energy cost as it involves only solar energy which is free of costs.

From the theoretical analysis found that increasing the ambient temperature will increase the productivity of system, which shows that system performs more distillation at higher ambient temperature.

Solar still productivity can also increase by use of reflector. The use of mirror reflector will increase the temperature of the solar still basin; such as increase in the temperature is because of the improvement in solar radiation concentration. The capital cost will be reduce by this solar still design.

The following section summarizes the key design aspects of solar still:

1) The factors such as location, type, quality of saline water availability of required materials economics etc. affect the selection of specific type of solar still.
2) The performance of solar still gets affected by design parameters like basin area, orientation of still, depth of water, temperature of inlet water, water-glass temperature difference.
3) The metrological parameters like availability of solar radiation, wind velocity and surrounding temperature play an important role in performance of solar still.
4) Solar desalination system is not available for commercial or domestic in spite of lot of advancements.
5) Addition of PCM increases productivity
6) Stepped Type solar still is more efficient than Basin Type

7.2 Future Scope:

1) In future work, two solar stills will design, constructing to compare distilled water productivity by using the solar desalination technique. Collect various materials required for construction of solar still. Make model as per designing model.
2) We will modify solar still with PCM is integrated with a double passes solar air collector {Modified Solar Still (MSS), with PCM and hot air injection} which consists of PCM reservoir, absorber surface, feed water tank, glass cover, insulation layer, double passes solar air collector, hot air distribution system, blower and measuring instruments and devices.
3) Solar still productivity can also increase by use of reflector. The use of mirror reflector will increase the temperature of the solar still basin; such as increase in the temperature is because of the improvement in solar radiation concentration. The capital cost will be reduced by this solar still design.
4) Carbon nanotubes (CNT), ED-CEDI, solar evaporation, and clathrate formation (freezing) are in a group of alternative technologies that offer a promising future for desalination technology. None are prevalent or commercialized in seawater desalination, and do not bear consideration as a full-scale desalination process at this time. However, although these technologies would not be placed into full-scale service at the proposed Plant in the near future; they could be candidates to consider for testing at it.

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