PERFORMANCE AUGMENTATION OF BASIN TYPE SOLAR STILL USING MINI SOLAR POND & SHALLOW SOLAR POND

A Dissertation Submitted in Partial fulfillment of requirements for the Degree

of

MASTER OF ENGINEERING

in

Thermal Engineering

Submitted by

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CERTIFICATE

I hereby declare that the seminar report entitled **"Performance augmentation of basin type solar still using mini solar pond & Shallow solar pond"** is an authentic record of my work carried out as requirements for the award of the degree of Master of Engineering in Thermal Engineering at, Thapar Institute of Engineering & Technology, Patiala under the supervision of **Dr. Madhup Kumar Mittal** (Associate Professor, Mechanical Engineering Department, Thapar Institute of Engineering & Technology). No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

(Sudhir Kumar Singh)

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Date: 29 June 2018

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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(SUDHIR KUMAR SINGH)

Abstract

A large number of world populations do not obtain clean drinking water. According to some Resources, by 2020 it's estimated that out of 7.5 billion human beings on earth, more than 2 billion human beings will face clean drinking water shortage. In recent days, Desalination is one of the most suitable methods for water distillation. This needed sufficient amount of energy in form of solar radiation as heat source to evaporate water thus segregating water vapour from contaminants present in it. In present study, the conventional basin type solar still has been modified to increase its productivity. Shallow solar pond and mini solar pond was used to supply additional heat to the basin of modified solar still in closed cycle mode using heat exchanger. Shallow solar pond was connected during sunshine hours in continuous and closed cycle mode of heat extraction, while mini solar pond was connected during night in batch and closed cycle mode of heat extraction. The performance of modified solar still coupled with shallow solar pond, by varying basin water depth (5cm to 7cm) has been compared with conventional basin type solar still. The performance of modified solar still coupled with shallow solar pond and mini solar pond has been investigated experimentally. Experiments have been performed during summer season of 2018. The maximum increase in productivity of modified solar still was 20.85 % at basin water depth of 6 cm. The increase in daily productivity of modified solar still coupled with shallow solar pond and mini solar pond was found to be 45.75 % over conventional basin type solar still.

Keywords: Solar still, mini solar pond, shallow solar pond, shallow solar pond, solar desalination

Contents

Nomenclature

Abbreviations

LCZ	Lower convection zone
NCZ	Non-convection zone
UCZ	Upper convection zone
CSS	Conventional solar still
MSS	Modified solar still
MSP	Mini solar pond
SSP	Shallow solar pond

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Chapter 1

INTRODUCTION

1.1 GENERAL

Water is a fundamental source of health and nutrition. It helps to keep people hydrated and gives body the nutrients they need. If human beings don't have fresh water, their bodies will have illness, sometimes leading to death. Clean and pure water is an essential thing for survival of mankind. 97% of the earth's water is salty and less than 2% is hard to reach. 0.014% of total earth's water is clean and easily reachable. In most parts of the world, water is available in saline as in coastal regions or brackish in nature and therefore not fit for human drinking. The total amount of easily reachable clean water on Earth is in the form of ground water or surface water (rivers and lakes). A large number of world populations do not obtain clean drinking water. According to some Resources, by 2020 it's estimated that out of 7.5 billion human beings on earth, more than 2 billion human beings will face clean drinking water shortage. Five years later in 2025, approximately 50 percent of the world population will be facing extreme water scarcity conditions. Unless water is not made clean from available brine water, the shortage will always be there. In recent days, solar desalination is a very appropriate technology by which we can produce fresh water.

1.2 SOLAR DESALINATION AND SOLAR STILL

Desalination is one of the most suitable methods for water distillation. This needed sufficient amount of energy in form of solar radiation as heat source to evaporate water thus segregating water vapour from contaminants present in it. Feed water in form of saline water is fed into the system to get clean water as output. The mechanism and size of desalination process is determined by the availability of source water and type of thermal energy available on that location. Desalination is a process that eliminates minerals from feed water sources such as ocean water, tap water.

1.2.1 Basic Principle of Solar Desalination

Figure 1.1 shows the principle energy transfer mechanism in a basin type solar still. A solar still works on basin principle of evaporation and condensation. The polluted water is filled in the basin of solar still and solar radiation passes from the transparent glass causing saline water to heat up and evaporates. Sun energy is incident on the basin liner is absorbed in it and transferred to the basin water by conduction and convection. Due to rise in basin water temperature, surface water gets evaporated. The vapour is condensed on the inner surface of transparent glass cover. While evaporating, water leaves all the impurities and germs in the basin. The evaporated clean water is condensed on the inner side of the glass cover and passes through the distillate channel on the bottom of glass cover. It is then collected in the container. Salt and impurities are left in the basin water of solar still. A solar still removes all gems, bacteria, salt and heavy metals from water.

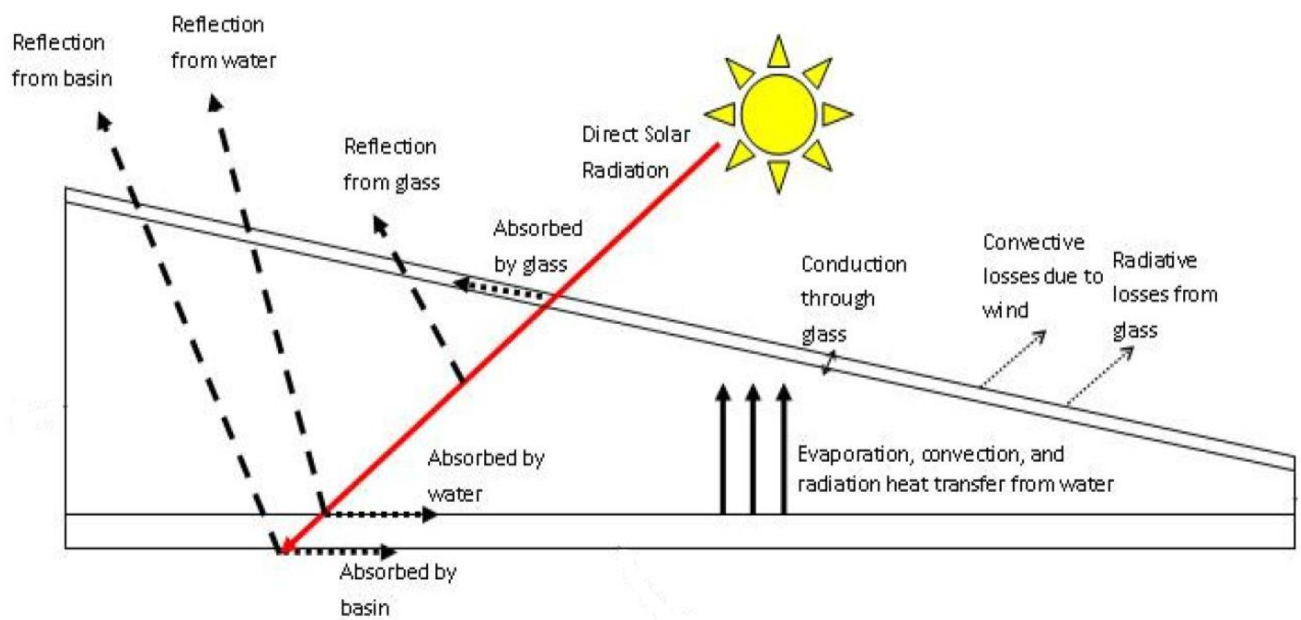

Figure 1.1 solar still indicating energy flow [5]

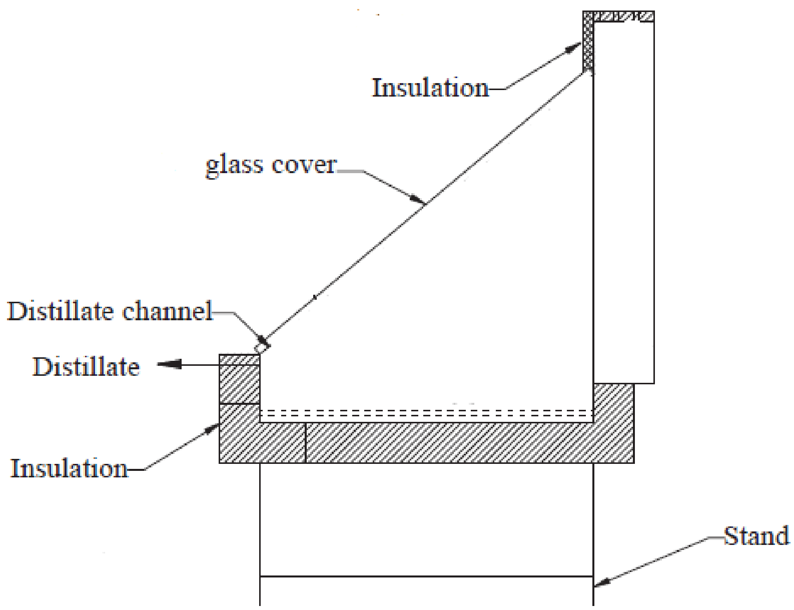

Figure 1.2 Basin type solar still [36]

A general process of distillation in solar stills is shown in Fig. 1.3. There are five processes which include solar energy absorption by saline water and basin liner, heat transfer from basin liner to saline water, heat transfer from saline water and condensing glass cover and heat loss from condensing glass cover to the surroundings. Water is vaporized from the surface of basin water. Vapour is carried to the glass by convection and diffusion, where latent heat of vaporization is liberated by condensation. Some heat trapped within the solar still is transferred to the glass by free convection. Heat from the water surface is released to the glass cover.

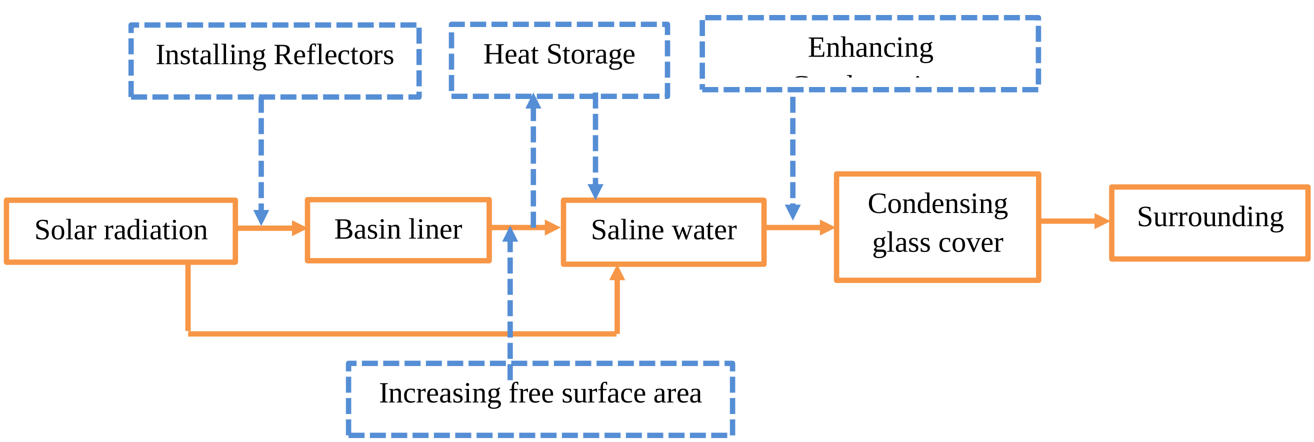

Figure 1.3 Process of distillation

1.2.2 Heat transfer process in solar still

The heat transfer in still can be categorised as internal and external heat transfer as shown in figure 1.4. The internal heat transfer occurs inside the solar still which consists of evaporation, convection and radiation. It includes heat transfer from basin water to inner side glass .This is responsible for fresh water in vapour form rejecting all the contaminant in the basin. The external heat transfer occurs outside the solar still which consists of conduction, convection and radiation. It includes heat dissipation from glass to surrounding and basin to ambient through insulation. External heat transfer from glass cover to surrounding is responsible for condensation of vapour. Higher the heat dissipation from glass to surrounding, the higher will be distillate from the still whereas lower the heat transfer from insulated wall side to surrounding, the higher will be productivity. Both internal as well as external heat transfers are advantageous but heat losses from insulation to surrounding are unwanted.

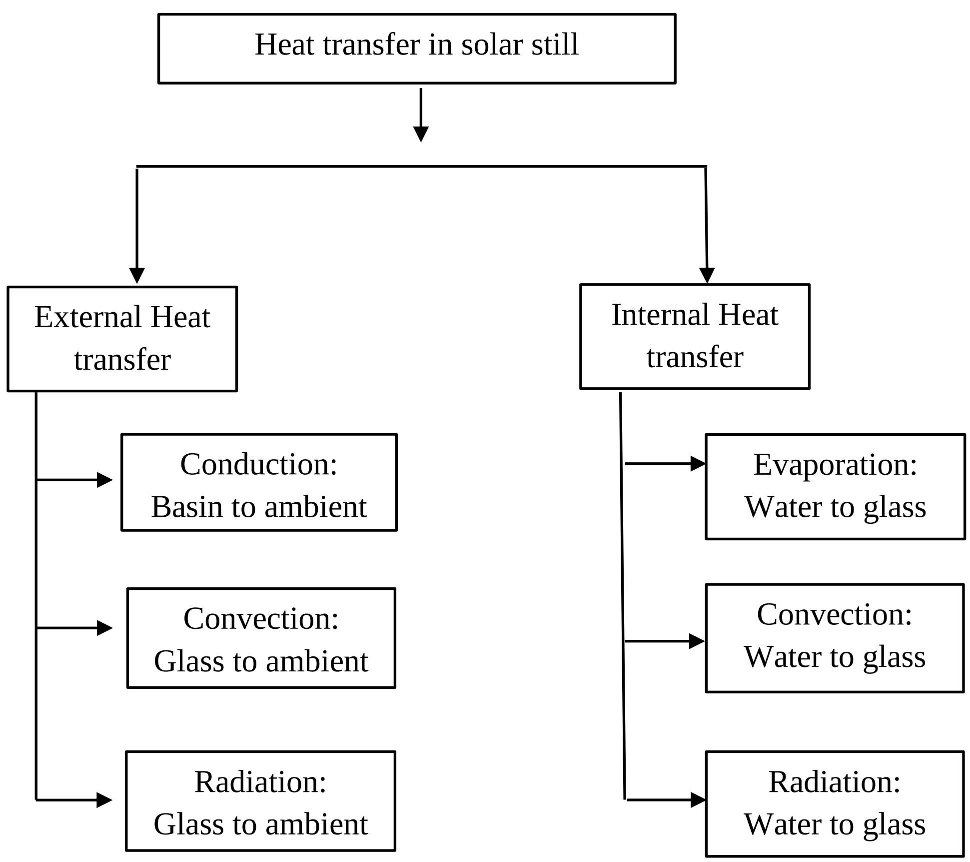

Figure 1.4 classification of Heat transfer in solar still [44]

1.3 CLASSIFICATION OF SOLAR STILL

Solar still are mainly categorized as passive and active still. On the basis of literature review, its classification is shown in figure 1.5. Passive solar still have only the solar radiation to heat the basin water. It does not have any external source of heat transfer. In active solar still an extra heat is delivered into the basin using some external source (such as mini solar pond, shallow solar pond, flat plate collector etc.) for faster evaporation.

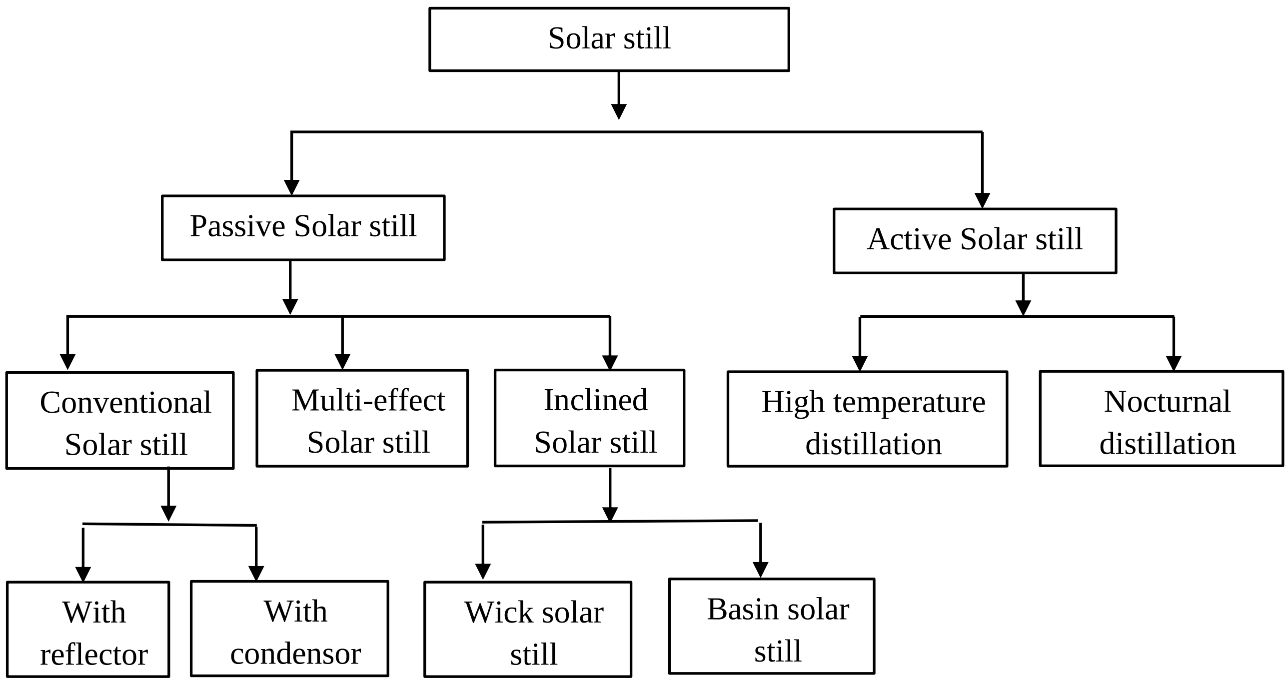

Figure 1.5 Classification of basin type solar still [44]

The main disadvantage of passive solar still is its lower productivity. From various researchers, it has been found that the overall system efficiency can be enhanced by decreasing basin water depth, maintaining the temperature difference between condensing glass cover and evaporating water surface. This can be achieved by raising basin water temperature or reducing glass temperature. The basin water temperature can be raised by providing the extra heat into the basin using some external source.

1.4 PARAMETER INFLUENCING SOLAR STILL PRODUCTIVITY

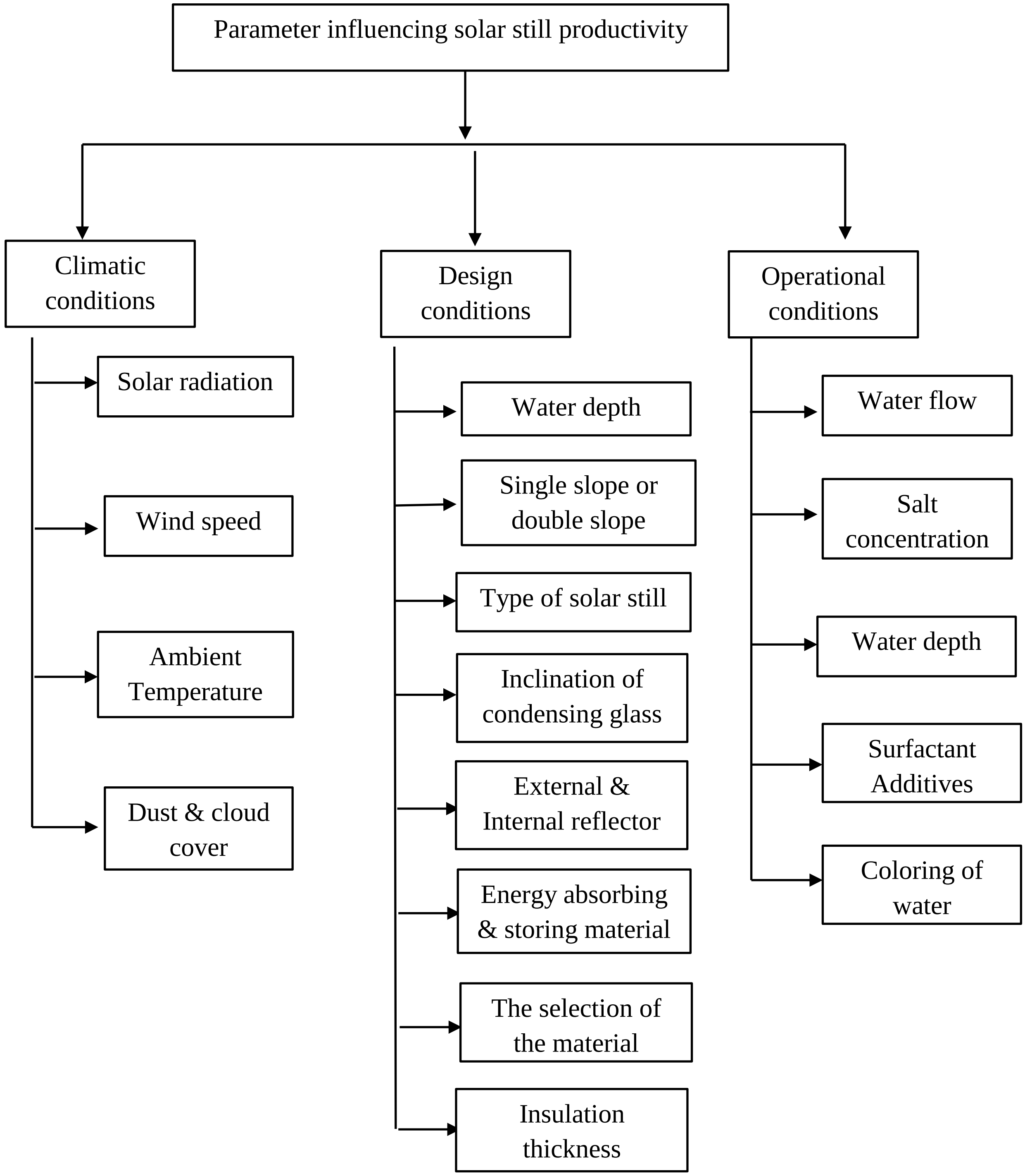

Figure 1.6 Parameters influencing the performance of solar still [43]

For better productivity of solar still, various improvement were advised by researchers:

- Reducing bottom and side loss
- Decreasing basin water depth.
- Using internal and external condensers
- Adding energy storage element inside basin
- Adding sponge cubes inside basin
- Condensing cover cooling
- Inclined solar still
- Increasing evaporative area

1.5 SOLAR POND

A solar pond is a heat storing device. Solar ponds is categorized into:

- Convective solar pond
- Non- convective solar pond.

Solar radiation is incident on the bottom surface of mini pond due to which water gets heated up. Because of difference in water density, heated water rises up by convection and there is heat transfer from upper surface to surrounding. To minimize this heat loss, density gradient is maintained with the help of salt. Increasing amount of salt is dissolved in the water from top to bottom due to which density increases with increase in depth from top.

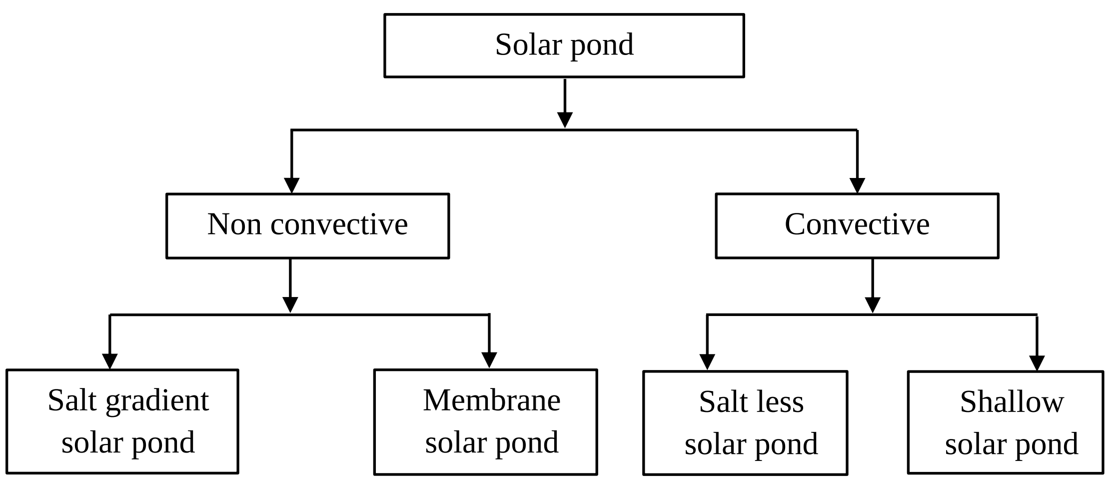

Figure 1.7 Classification of solar pond

1.5.1 Salt gradient solar pond

It consists of three zones namely lower convection zone, non-convective zone and upper convective zone shown in figure 1.8. Lower convection zone also called as storage region, has uniform and highest salt gradient close to saturated salt. Due to high salt solution, the specific heat of water increases in this region. Therefore, heat storage capacity increases. Heat transfer from storage region is avoided, since natural convection is prevented in non-convective region. In non-convective region salt gradient or density gradient increase with depth, due to which the heat transfer from storage zone region is prevented. Temperature gradient is formed in non-convective region. The salt gradient in upper convective region is least close to the water. The temperature in this region remains constant almost equal to ambient temperature. The heat stored in storage region is extracted in two ways. Firstly, though heat exchanger. Secondly, extracting the hot salty water from upper layer of storage region.

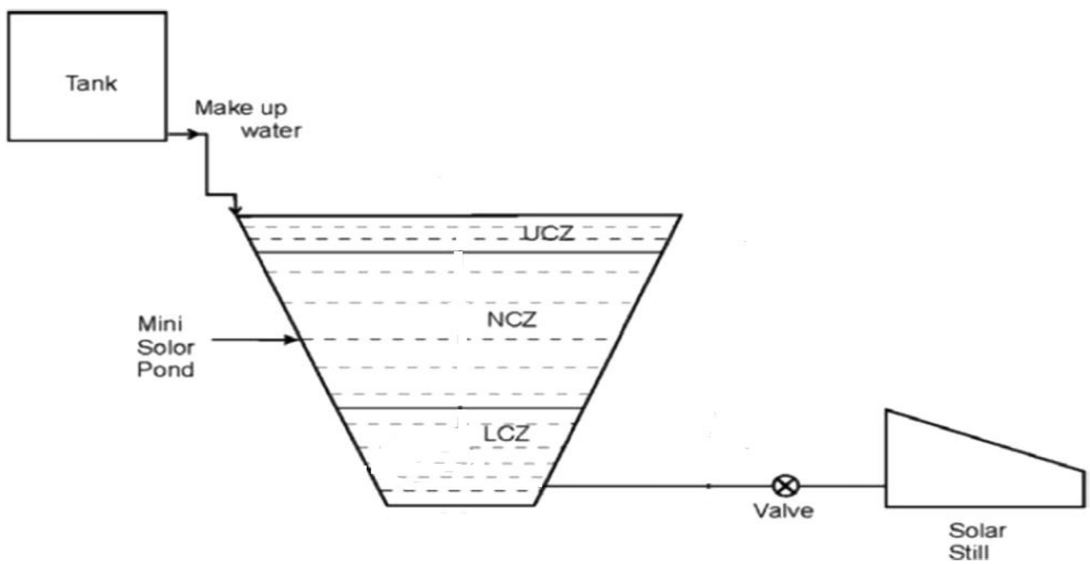

Figure 1.8 Salt gradient solar pond [9]

1.5.2 Salt less mini solar pond

It is designed to minimize the conduction, convection and radiation loss from the top by providing double glass cover. The covering of solar pond prevents thermal losses from top surface.

1.5.3 Shallow solar pond

This is a heat storage body having very low depth of water, generally 2-10 cm. It prevents evaporation but permits convection. To avoid the evaporative loss, the lower glass is kept in touch with water surface. There are many ways of heat transfer from shallow solar pond to solar still. Open cycle in batch or continuous mode and closed cycle in continuous or batch mode. In batch mode, heat is supplied for a particular interval of time. In continuous mode, heat is supplied throughout. In closed cycle, heat is extracted by placing heat exchanger inside solar pond.

1.6 RESEARCH OBJECTIVE

Experimental investigation has been carried out to evaluate the performance of basin type solar still coupled with mini solar pond shallow solar pond, and conventional basin type solar still with the following specific objectives.

1. To investigate the performance of basin type solar still coupled with shallow solar pond and compare with the performance of conventional basin type solar still.
2. To examine the performance of basin type solar still coupled with shallow solar pond by varying the basin water depth of solar still.
3. To test the performance of basin type solar still coupled with shallow solar pond and mini solar pond, and compare with the performance of conventional basin type solar still.

Chapter 2

LITERATURE REVIEW

The basin type solar still with no modifications has low productivity. Solar radiation through transparent glass cover is incident on the basin liner and side wall of solar still and absorbed in it and transferred to the basin water. Due to rise in basin water temperature, surface water gets evaporated. The water vapors get condensed on inner side of glass cover. During night, distillate is obtained, due to the stored energy in the basin water. A vast literature review has been done for various types of stills. A various attempt were made by researchers to enhance its efficiency. Some of these are described below.

2.1 SOLAR STILL WITH EXTERNAL THERMAL ENERGY SOURCE

External heat from mini solar pond, shallow solar pond, solar concentrators and flat plate collectors were used to raise the productivity of the solar still.

A. Alcaraz et al. [1] conducted the experiments on the solar pond by taking out heat from non-convection and lower convection region of salinity-gradient solar pond. He observed that when the heat was extracted out by the lateral heat exchanger as compared to extraction of heat normally from storage zone, the efficiency of the solar pond increases. Effectiveness of Heat extraction during December 2013 (60%) was lower as compared to July 2018 (80 %).

M.M.Ould Dah et al. [2] investigated the effect of the heat withdrawal mode on the efficiency of a mini solar pond. They concluded that, to increase the performance of the mini pond, it must be insulated properly to avoid bottom and side loss. During the hot month of the year, the mini pond was found to deliver heat at temperature of 49-60 ^{0}C. The efficiency of mini pond could be improved by removing heat from the non-convection region in place of storage region. However removing heat from the non-convection region minimizes the stability of the lower region.

Bozkurt et al. 2014 [3] studied the influence of the covers (polycarbonate, mica and glass) on the cylindrical solar pond. Solar pond with glass cover has greatest energy efficiency with 17.86% while that of polycarbonate was 16.95% and mica 15.86%.

Badran & Abu-Khader [4] found that the increase in solar intensity or ambient temperature results in an increase in productivity of solar still. Productivity of solar still was enhanced by 25.5 % on reducing the basin water depth from 4 cm to 2 cm. The maximum efficiency was obtained in afternoon because of peak solar intensity at that time. Due to higher solar radiation and atmospheric temperature, the overall heat loss coefficient increases till afternoon.

Refalo et al. [5] has discussed the effect of climatic conditions on basin type solar still. The productivity rises with rise in atmospheric temperature from 10 °C to 30 °C, by an amount of 11% to 47%, depending on insulation and wind speed. The productivity was 81 ml/MJ at the total solar radiation of 10.5 MJ/m^2/day and 130 ml/MJ at the total solar radiation of 30 MJ/m^2/days. The productivity was enhanced with rise in ambient temperature. Productivity of solar still decreases with increase in wind speed. A rise in wind speed from 1 m/s to 5 m/s causes a fall in productivity of still between 8% and 15%, depending on ambient temperature and insulation.

Omara & Kabeel [6] studied the basin type solar stills having sand in basin. The productivity of the solar still enhanced with decrease in depth of basin water above the sand beds. The productivity of the solar still rises with decrease in height of sand beds. The maximum productivity of solar stills having sand in basin is obtained at zero depth of basin water above the sand beds and sand beds height of 0.01 m. The productivity of solar still having yellow sand in basin was enhanced by 17% and that with black sand in basin was enhanced by 42% as compared to the CSS.

A.A. El-Sebaii et al. [7] studied the productivity of basin type solar still connected with shallow pond. The basin area of still was 1 m^2. Shallow pond was covered with transparent glass. The depth of shallow pond was 0.088 m. To eliminate heat loss, lower glass was in touch with water surface. A heat exchanger of copper was inside the shallow solar pond. Heat transfer takes place in open mode inside the solar still. Due to gain in basin water temperature, the productivity of MSS connected with SSP is better than CSS. SSP enhances the nocturnal performance of solar still. The optimum basin water depth was 3 cm and flow rate of water inside heat exchanger was 0.0009 kg/s. The rise in productivity of MSS was 51% and efficiency was 45% as compared to CSS.

A.A. El-Sebaii et al. [8] investigated the productivity of solar still connected with a SSP. The basin area of still was 1 m^2. SSP was covered with double glass. A heat exchanger of copper was inside the SSP. Energy transfer takes place in close mode inside the solar still. Productivity of CSS reaches zero in night. However connecting MSS with SSP produces distillate continuously during off sunshine hours, this was due to the heat gained from the shallow pond. The efficiency of modified still was 45% and that of conventional solar still was 19.6%.

V. Velmurugan et al. [9] studied the performance of Solar still connected with mini pond. It was concluded that for enhancing the temperature of storage region, the optimal feeding salt is 80 g per kg of water. The enhancement in productivity was obtained 27.5%, when the mini pond is coupled with the still. The rise in productivity was 13.8%, when basin of solar still had sponges. The productivity of a solar still having sponges in basin and connected to mini pond was 58% as compared to that of CSS.

Velmurugan et al. [10] investigated the performance of fin type stepped solar still having pebble, sponge in the basin and solar still with fin and having sponge, sand and black rubber in the basin. Both the solar stills were connected with solar pond as external heat source. The enhancement in productivity of step solar still having pebble, sponge, fin in its basin and connected with mini solar pond was found to be 100% as compared to stepped solar still alone.

M. Appadurai et al. [11] has discussed the productivity of solar still connected with mini pond. Both, still as well as mini pond had fin in the basin to enhance the evaporative surface area. The productivity of solar still rises with rise in solar intensity. When solar still is connected with mini pond, its productivity enhances by 27.5 %. When fins are attached in the basin of solar still, its productivity rises by 45.5 % due to the increase in area of absorber plate. When solar still having fin is coupled with fin type mini solar pond, its productivity increases by 50% due to the increase in surface area of mini pond basin and still basin.

Singh and Tiwari [12] has discussed the performance basin type solar stills for various weather conditions in India. They concluded that, for maximum productivity, the optimum slope angle of the transparent cover of solar still was the latitude of that specific place.

Ranjan & Kaushik [13] has described active solar still connected with mini pond. For solar intensity from 100 to 500 W/m^2, the daily rise in productivity of modified solar still was 9.5 L/m^2 and rise in energy efficiency was obtained 38.63 %. For solar intensity of 500 W/m^2, the highest daily production of the modified solar still during 24 hours operation was approximate 16.76 L/m^2 and energy efficiency was 52.93 %.

2.2 SOLAR STILL HAVING EXTERNAL AND INTERNAL REFLECTORS

Maximum solar radiation should be incident to basin liner to enhance the solar still output. Internal reflectors were utilized on the internal walls of solar still to maximize the reflection of solar intensity incident on the walls. The external reflector helps to maximize the solar intensity incident on the transparent glass cover.

Tanaka [14] investigated the solar still with flat plate type external reflector and internal reflectors at the inner walls of solar still. The enhancement in productivity was obtained as 62% than solar still without reflectors.

Boubekri et al. [15] has discussed the productivity of solar still connected with solar water heater and external as well as internal reflectors. The rise in productivity was 138% over the conventional solar still.

Tanaka and Nakatake [16] has described the performance of solar still connected to external reflector at 15° & internal reflectors. The experiments were performed on winter days. The rise in productivity was approximately 2.4 times as compared to conventional solar still.

Tanaka and Nakatake [17] has discussed the performance of solar still having internal and external reflector. The solar still was basin type with single slope. The increse in productivity was 48% as compared to CSS.

Dev et al. [18] studied experimentally the solar still having curved internal reflector inside the basin. The productivity of modified still was greater than that of CSS.

Khalifa and Ibrahim [19] examined the performance of a solar still by varying the inclination of external reflectors. The experiments were performed on winter days. The internal reflector was set fixed while external reflector was varied at an angle of 0°, 10°, 20° and 30° from the vertical. They conclude that, the productivity of solar still having external reflector tilted at 20° from vertical was approximately 2.5 times higher as compared to conventional basin type solar still.

Tanaka [20] investigated the performance of solar still with external reflector by varying the height of external reflector and slope of transparent glass. For maximum productivity of solar still, the height of external reflector was half to that of solar still and slope of transparent glass was 50°. They obtained the maximum increse in productivity of 67% as compared to conventional solar still.

2.3 ADDING HEAT STORAGE MEDIUM IN SOLAR STILL BASIN

The heat in the basin of solar still was stored by adding some heat storage medium such as sand, pebbles etc. These elements were heated during sunshine hours due to which heat energy is stored. The stored energy is utilized to get distillate in off-sunshine or cloudy hours.

Tabrizi and Sharak [21] studied the performance of basin type solar still by adding sand. The sand inside the basin reserves the heat to supply during off-sunshine hours. They obtained the rise in productivity during off- sunshine hours as compared to CSS.

El-Sebaii et al. [22] studied the basin type solar still having sand inside the basin. The sand stores heat to deliver during night. They obtained the increase in productivity during off-sunshine hours because of heat release from sand .The gain in productivity was 24% as compared to CSS.

2.4 INCREASING THE RATE OF CONDENSATION

Distillate productivity can be enhanced by increasing the condensation.This can be attained by enhancing the cooling rate of vapour.

El-bahi and Inan [23] studied the performance of solar still with evaporator and condenser individually. The evaporator with double glass covers is coupled with condensor. A reflector was also placed on evaporator to maximize the incident solar intensity . The condensing glass cover was inclined to collect the distillate. They obtained the rise in productivity. The distillate obtained was 4 kg/m^2/day which was enhanced to 6 kg/m^2/day with water cooled condensing glass cover. The rise in efficiency was 22% with water cooled condensing glass cover.

El-bahi and Inan [24] has described the performance of solar still connected with condensor. Solar still was coupled with external reflector and was covered with transparent glass at an angle of 4°. The basin of solar still was coupled with an external condenser having tilted glass cover. Some water vapour was condensed on the still's glass cover while remaining vapours was condensed on condensor glass cover. The distillate output obtained was 70 kg/m^2/day.

Ahmed [25] investigated the performance of a solar still with an inner condenser. The condensor is placed on the top side of the solar still . Cooled water was passed on the copper tube condenser. The rise in productivity was 10% as compared to CSS.

2.5 INCREASING EVAPORATIVE AREA OF BASIN WATER

The evaporation rate can be enhanced by maximizing the surface area of water by adding wicks, sponges, fins etc. in still's basin. Due to this inertia of surface water decreases and hence rate of evaporation rises.

Srivastava and Agrawal [26] studied experimentally the solar still with floating wick inside the basin water of solar still. The wicks were made of wrapping jute cloth on polystyrene sheet. The jute cloths were colored with black dye. They found that productivity of solar still varies with the basin water depth. The rise in productivity was 68% as compared to CSS.

Velmurugan et al. [27] studied the solar still with fins, floating wicks and sponges inside the basin. The rise in productivity was 15.3% for sponges in basin, 29.6% for inclined wicks and 45.5% for fins in basin as related to CSS.

Alaian et al. [28] studied experimentally solar still by placing pin finned wick inside basin. The rise in productivity was 23% as related to CSS.

Matrawy et al. [29] studied the performance of a solar still connected with external reflector and wick in basin. The rise in productivity was 34% as related to CSS.

Abu-Hijleh and Rabab [30] investigated the efficiency of solar still with sponge inside the basin water. Surface area was increased by adding sponges in basin water. The enhancement in productivity was 270% as related to CSS.

Omara et al. [31] studied the solar still with floating wick inside the basin water of solar still and having internal reflector. The enhancement in productivity was 145% as compared to CSS.

Nafey et al. [32] investigated the solar still with floating aluminium plate in a basin. The aluminium plate was painted black. The experiments were performed at various basin water depths. The maximum rise in productivity was 38% at 6 cm basin water depth as compared to CSS.

2.6 SOLAR STILL WITH INCLINED WICK

Inclined surfaces receives more solar radiation than placed normal to the incident solar radiation. For maximum solar intensity, the suface should be inclined to at an angle same as latitude of that location. The wick on the inclined surfaces maximizes the exposed surface of water and hence rate of evaporation rises.

Tanaka [33] studied the a inclined wick solar still with internal reflector. Internal reflector was fixed on the bottom surface of solar still to maximize the solar intensity incident on the wick surface. The enhancement in productivity of inclined wick solar still with reflector was 13% as compared to inclined wick solar still without reflector.

Tanaka and Nakatake [34] studied the inclined wick still having flat plate reflector. The experiments were performed on winter days. The productivity of modified still can be enhanced by increasing the reflector length along with tilting the reflector. The rise in productivity was 27% with same length of inclined solar still and reflector as compared to conventional solar still.

Tanaka and Nakatake [35] studied inclined wick solar still with external reflector. The external reflector was placed on the top side of solar still. The experiments were conducted in summer and winter days at a latitude angle of 30^0 N. The enhancement in productivity of inclined solar still with reflector was obtained for winter as compared to inclined solar still without reflector. The increase in productivity for summer and winter days was 9%.

2.7 MOTIVATION FOR THIS RESEARCH

There are many improvements have been suggested by various researchers for improving the productivity of solar still but there are some gaps in the development of this technology. Some of which are explained below -

- The study of the performance of a single basin solar still integrated with shallow solar pond with different basin water depth has not been done yet.
- The combined study of shallow solar pond and mini solar pond on the performance of the still has not been done yet.
- In an open cycle continuous mode large amount of energy losses to the atmosphere. It can be saved by transferring the heat in closed cycle mode of heat exchanger.

Chapter 3

EXPERIMENTAL SETUP AND PROCEDURE

3.1 EXPERIMENTAL SETUP

3.1.1 Basin type solar still

Basin of solar still is made of stainless steel because of its high resilience and ductility while frame of solar still is made of mild steel. A black painted rubber liner of thickness 0.01 m is kept inside the basin to absorb more heat.

Figure 3.1 Modified still (left side) and reference still (right side)

The side wall of the solar still is insulated with glass wool while basin is insulated with polyurethane sheet to prevent the heat loss to surrounding. Inside wall of solar still is colored white to enhance the reflectivity of solar intensity. Distillate channel to collect the distilled water is provided at the bottom of glass cover. The distillate channel is made of polycarbonate sheet.

Table 3.1 Components of solar still

S. No.	Still component	Dimensions
1	Basin area	1.5 m x 0.77 m
2	glass area	1.47 m x 0.9 m
3	Inclination angle of glass	40°
4	Glass thickness	0.005 m
5	Insulation thickness	0.125 m

3.1.2 Mini solar pond (MSP)

A trapezoidal shaped MSP with double glass cover is shown in figure 3.2. Solar pond was made of mild-steel sheet (0.003 m thick) having height of 1 m, top surface area of 2.6 m^2 and bottom surface of 0.5 m^2. In order to reduce the heat transfer from walls, a 0.15 mm of insulation is done by glass-wool. This glass wool is covered with polycarbonate sheet of thickness 1 mm.

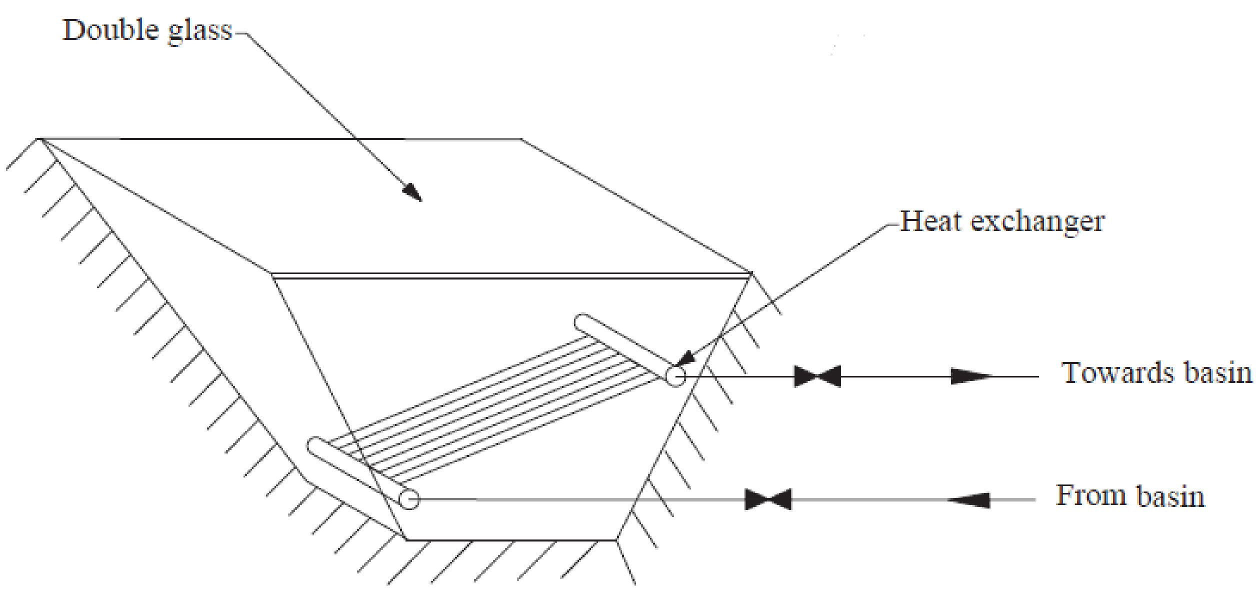

Figure 3.2 mini solar pond

Anti-corrosion paint was painted on the inner surface of wall to avoid the corrosion. The inside surface of solar pond is colored black to maximize the absorbed solar radiation. A black painted rubber liner of thickness 0.01 m is kept inside the basin to absorb more heat. Two glass of .005 m each thickness is used to cover the pond, to avoid the heat loss from upper surface of water. A gap of .01 m is maintained between both glasses. The volume of water inside MSP is 600 litre. A heat exchanger of .0127 m outer diameter and 0.915 m long was installed inside MSP, to transfer heat to MSS. The water is circulated by a pump having flow rate of 6.5 liter per minute and power of 50 W. T- type thermocouples were placed at a depth of 0.2, 0.3, 0.5, 0.6, 0.7 m from the bottom to measure the heated water. The average pond water temperature is calculated.

Table 3.2 Dimensions of mini pond

S. No.	**Mini Pond component**	**Dimensions**
1	Top surface size	1.625 m x 1.625 m
2	Bottom surface size	0.710 m x 0.710 m
3	Height	0.9 m
4	Volume of water	600 litre
5	Thickness of glass cover	0.005 m
6	Insulation thickness	0.15 m
7	Heat exchanger length	0.915 m
8	Heat exchanger outer diameter	0.0127 m

3.1.3 Shallow solar pond (SSP)

shallow solar pond with double glass cover is shown in figure 3.3. It was constructed at the solar energy lab, Thapar Institute of Engineering & Technology, Patiala. A shallow solar pond of 1.15 m^2 area and 5 cm depth is made of galvanized-iron sheet of 3 mm thickness.

Figure 3.3 Shallow pond with double glass cover

The side and bottom walls of shallow solar pond were insulated with polyurethane sheet of thickness 101.6 mm to prevent the heat loss to surrounding. The inner surface of pond is colored black to enhance the solar radiation incident on it. SSP was covered with double glass cover to avoid the loss from upper layer of water. The thickness of single glass cover is 5 mm and the gap of 1 cm between both glass cover is maintained with rubber. A heat exchanger of copper with 12.7 mm of outer diameter and 6.26 m of length is installed inside SSP to transfer heat to MSS. The working depth of water in shallow pond is 2 cm.

Table 3.3 Dimensions of shallow solar pond

S. No.	component	Dimensions
1	Basin Area	1.29 m^2
2	Working depth of water	2 cm
3	Volume of water	25.8 litre
4	Thickness of glass cover	5 mm
5	Heat exchanger length	6.26 m
6	Heat exchanger outer diameter	12.7 mm
7	Insulation thickness	101.6 mm

3.2 MEASURING INSTRUMENTS

Table 3.4 Instruments

S. No.	Instruments	Measuring range	Accuracy
1	Pyranometer	0 - 4000 w/m^2	1 W/m^2
2	Thermocouple (T type)	-120 ^{0}C to 200 ^{0}C	0.5 ^{0}C
3	Digital weighing machine	0 - 5 kg	0.1 g
4	pH meter	0 - 14 pH	0.02 pH
5	TDS meter	0.1 ppm - 200,000 ppm	2 % of reading

3.2.1 Pyranometer

It measures global solar radiation intensity on glass cover, shown in Figure 3.4. Its measuring range is 0 - 4000 W/m^2. The solar intensity data was logged at set interval of 10 min, by a Logbox SD data logger.

Figure 3.4 Pyranometer

3.2.2 Digital Data Logger

Temperature of various components of shallow solar pond, mini solar pond and solar still were measured by T-type thermocouple which was displayed in Data Logger, shown in figure 3.5. The time interval of 10 min was set in data logger.

Figure 3.5 Digital data logger

Distillate from modified solar still and conventional solar still were hourly weighed on digital weighing machine, between 8:00 AM to 8:00 PM. The distillates from 8:00 PM to 8:00 AM were measured next day in the morning.

3.3 EXPERIMENTAL PROCEDURE

A diagram of MSS connected with MSP and SSP is shown in figure 3.6. The experiments were carried out at Thapar institute of Engineering and Technology Patiala (30.35^0 N latitude & 76.36^0 E longitude). Before starting the experiments, both stills were calibrated under same operating conditions to check the difference in distillate. Calibration was done by removing all the modification done in modified solar still. Before beginning of experiments, basin of both stills was filled with same depth of water.

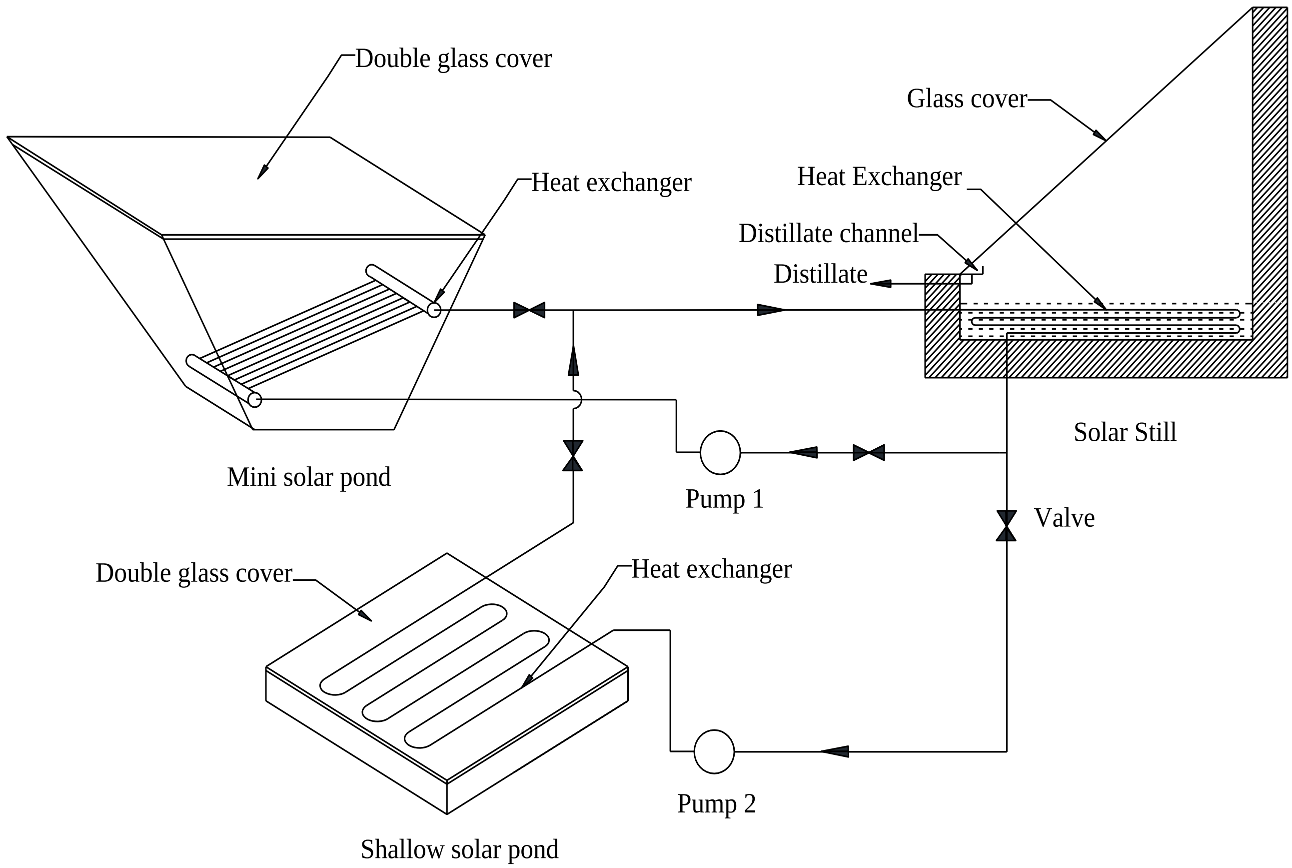

Figure 3.6 Line diagram of MSS coupled with MSP and SSP

In the present study, experiments were conducted from 8 am - 8 am next day. Distillates from both the still were measured on hourly basis between 8 am to 8 pm while distillate during 8 pm to 8 am next day was measured once at 8 am next day. The distillate from conventional still between 8 pm to 8 am next day is due to storage of energy while distillate from modified still during this period is due to both storage & externally supplied energy. Before starting new experiment, modified still & conventional still were filled at same depth. The stored energy from SSP was circulated through heat exchanger to MSS during 8 am to 8 pm with the help of water pump having flow rate of 1.2 liter per minute. The storage energy from MSP was circulated in closed cycle mode through heat exchanger to modified still during 12 am – 2 am and 4 am – 6 am with the help of automatically switch operated water pump having flow rate of 6.5 liter per minute. The solar intensity (W/m^2) on glass was measured by pyranometer. T-type thermocouples were used to determine the temperature at various locations of SSP, MSP, MSS and CSS.

Figure 3.7 MSS (left side) coupled with MSP and SSP with CSS (right side)

The experiments are carried out in two parts. In first part of experiments, solar still at various basin water depths (7 cm, 6 cm, 5 cm, 4 cm) is connected to SSP (8 am to 8 pm), as external heat source, to find the maximum gain in productivity of MSS over CSS. In second part of experiments, solar still at optimum basin water depth (6 cm) is connected to SSP (8 am - 8 pm) and MSP (12 am - 2 am and 4 am - 6 am), as external heat source, to find the productivity of MSS over CSS.

Case 1 : MSS at various basin water depth (7cm,6cm,5cm,4cm) is coupled with SSP(8am–8pm).

1.1 : Both the still with basin water depth of 7 cm

1.2 : Both the still with basin water depth of 6 cm

1.3 : Both the still with basin water depth of 5 cm

1.4 : Both the still with basin water depth of 7 cm

Case 2 : MSS at basin water depth of 6 cm is coupled with SSP (8am–8pm) and MSP (12 am - 2 am and 4 am - 6 am).

Chapter 4

RESULTS AND DISCUSSION

4.1 TEST RESULTS OF CASE 1: EFFECT OF VARYING BASIN WATER DEPTH

As mentioned earlier, the experiments were performed by varying basin water depth of solar still. Before beginning of experiments, basin of both, MSS as well as CSS were filled with same depth of water. The depth and volume of water in SSP was 2 cm and 25.8 litre respectively. The stored energy from SSP was circulated through heat exchanger to MSS during 8 am to 8 pm. Experiments were conducted from 8 am to 8 am next day.

4.1.1 Stills having basin water depth of 7 cm

Experiment was performed on 23th May 2018. At the beginning of this experiment, basin water depth of CSS and MSS was 7 cm. The hourly variation of ambient temperature and solar radiation intensity on 23 May, 2018 is shown in figure 4.1.

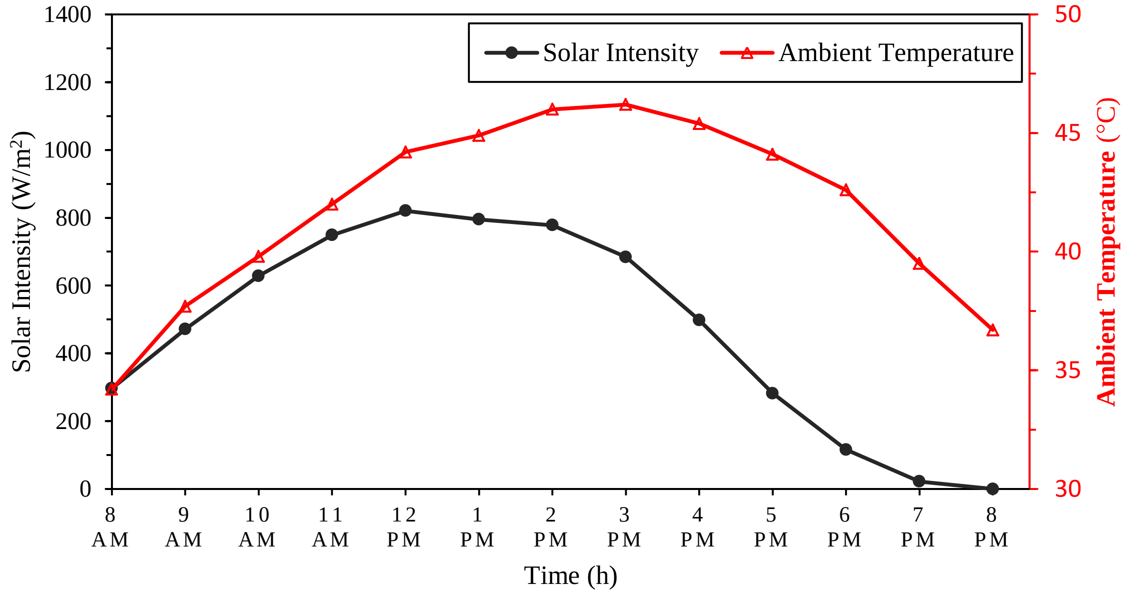

Figure 4.1 Variation of ambient temperature and solar intensity on 23 May 2018

The maximum solar intensity was 820 W/m^2 at 12 PM while maximum ambient temperature was 46.2 ^{0}C at 3 PM. The variation of basin water temperature of MSS, CSS and SSP for the 24 hour period is shown in figure 4.2. The basin water temperature of MSS remains high as compared to that of CSS throughout the day, because of the additional heat supply to the MSS from SSP from 8 am to 8 pm. The basin water temperature of MSS and CSS rises till 4 pm due to high solar intensity. The maximum basin water temperature of MSS was 64.4 ^{0}C while that for CSS was 62 ^{0} C. The basin water temperature of SSP rises till afternoon. The maximum basin water temperature was 85 ^{0}C at 3 pm. There is sharp rise in basin water temperature from 8 am to 1 pm due to the rise in solar intensity in afternoon. After 3 pm its temperature begins to fall, due to decrease in solar intensity and heat loss from upper glass cover along with side walls.

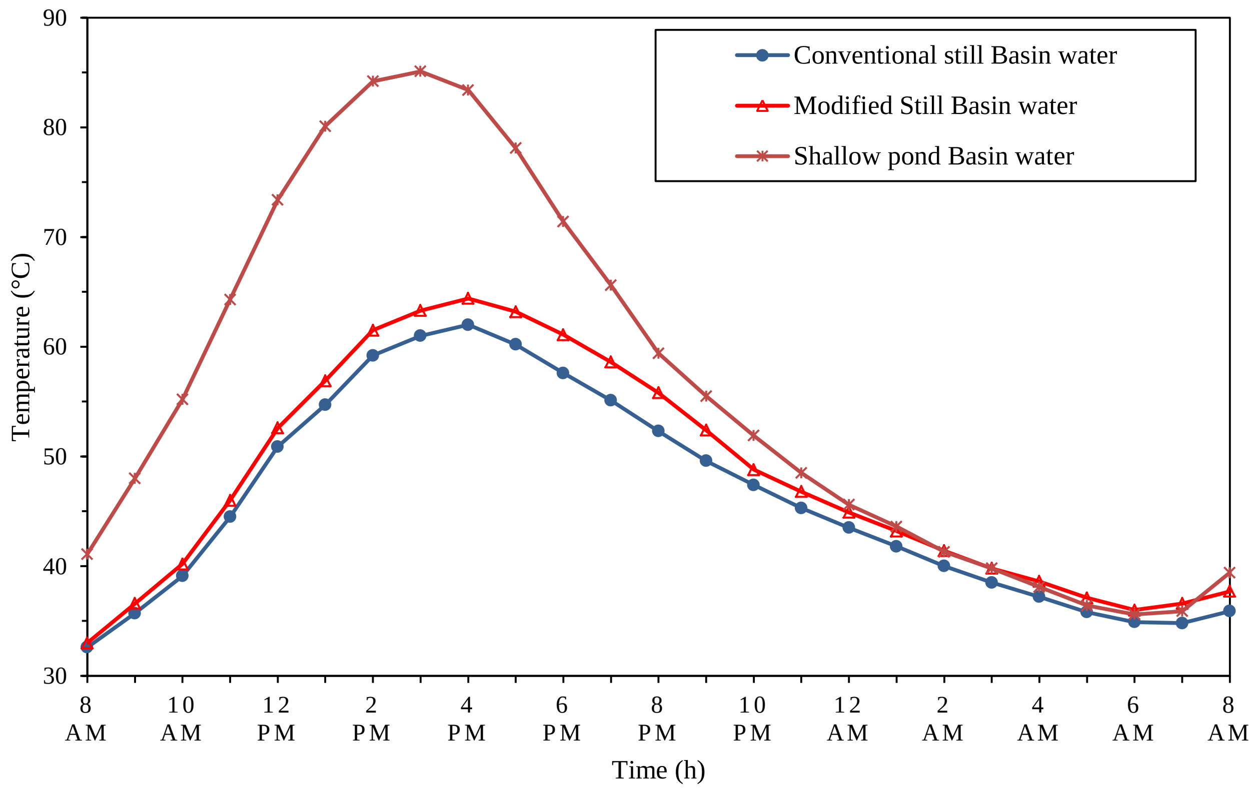

Figure 4.2 variation of basin water temperature of MSS, CSS and SSP

The cumulative distillate output of MSS and CSS is shown in figure 4.3. Productivity of MSS was greater than that of CSS. The distillate output of CSS for 24 hour was 2.55 kg/m^2 while that for MSS for 24 hour was 2.96 kg/m^2. The increase in productivity was 16 % as compared to CSS.

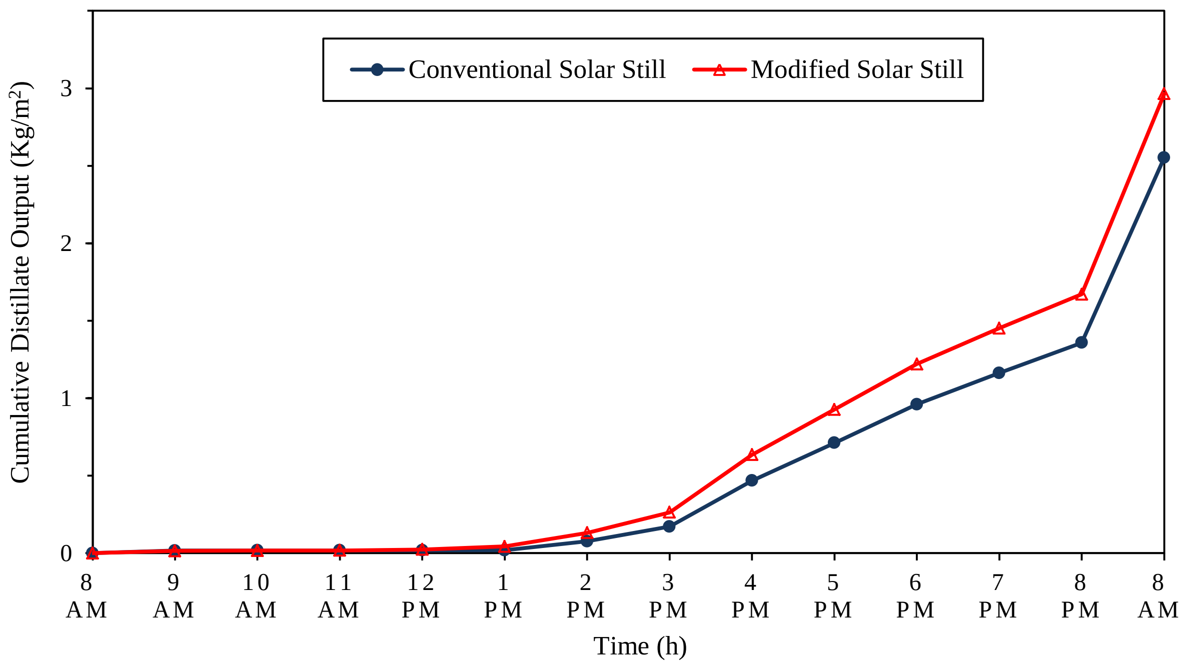

Figure 4.3 Variation of cumulative distillate output of conventional still and modified still

4.1.2 Stills having Basin water depth of 6 cm

Experiment was performed on 30th April 2018. At the beginning of this experiment, basin of both the stills, i.e. conventional and modified stills were filled with 6 cm water depth. The variation of ambient temperature and solar radiation intensity is shown in figure 4.4. The maximum solar intensity was 897 W/m^2 at 1 PM while maximum ambient temperature was 44.4 ^{0}C at 4 PM.

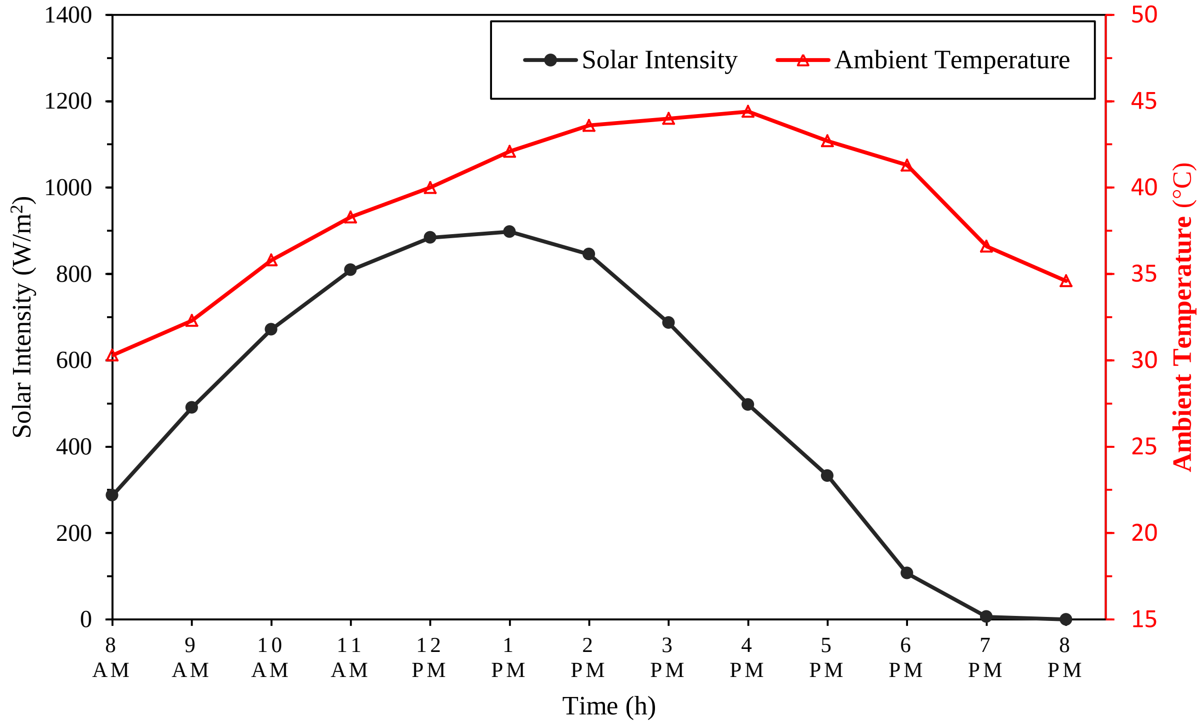

Figure 4.4 Variation of ambient temperature and solar intensity on 30 April 2018

The variation of basin water temperature of MSS, CSS and SSP for the 24 hour period is shown in figure 4.5. The basin water temperature of MSS remains high as compared to that of SSP throughout the day, this is because of the additional heat supply to the MSS from SSP. The basin water temperature of MSS and CSS rises till 4 pm due to high solar intensity. The max basin water temperature of MSS was 68.1 ^{0} C while that for CSS was 64.6 ^{0} C. The basin water temperature of SSP rises till afternoon. The maximum basin water temperature of CSS was 84 ^{0} C at 3 pm. There is sharp rise in basin water temperature of SSP from 9 am to 1 pm, due to the rise in solar intensity in afternoon. After 3 pm its temperature begins to fall, due to decrease in solar intensity and heat loss from upper glass cover along with side walls.

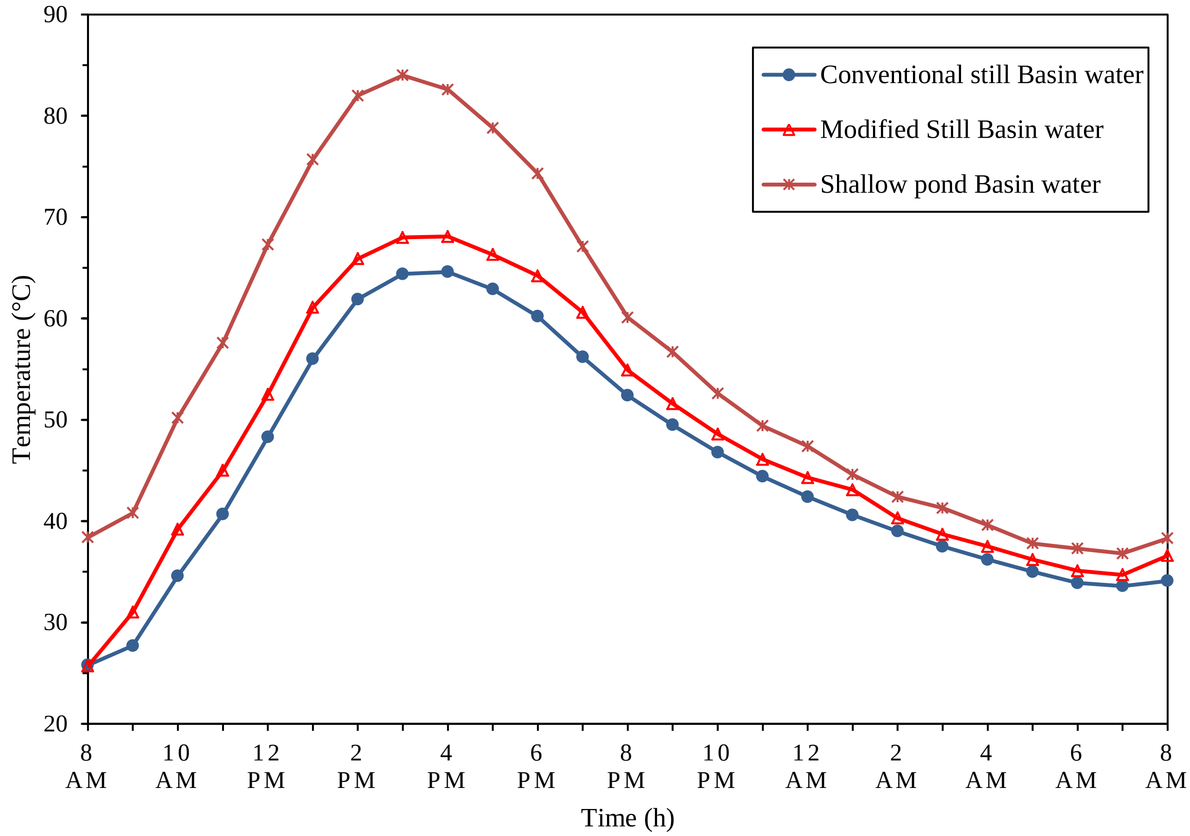

Figure 4.5 variation of basin water temperature of modified still, conventional still and shallow pond

The variation of cumulative distillate output of conventional and modified solar still is shown in figure 4.6. It can be observed that productivity of MSS was greater than that of CSS. The distillate output of CSS and MSS for 24 hour was 2.63 kg/m^2 and 3.18 kg/m^2 respectively. The increse in productivity was 20.91 % as compared to CSS.

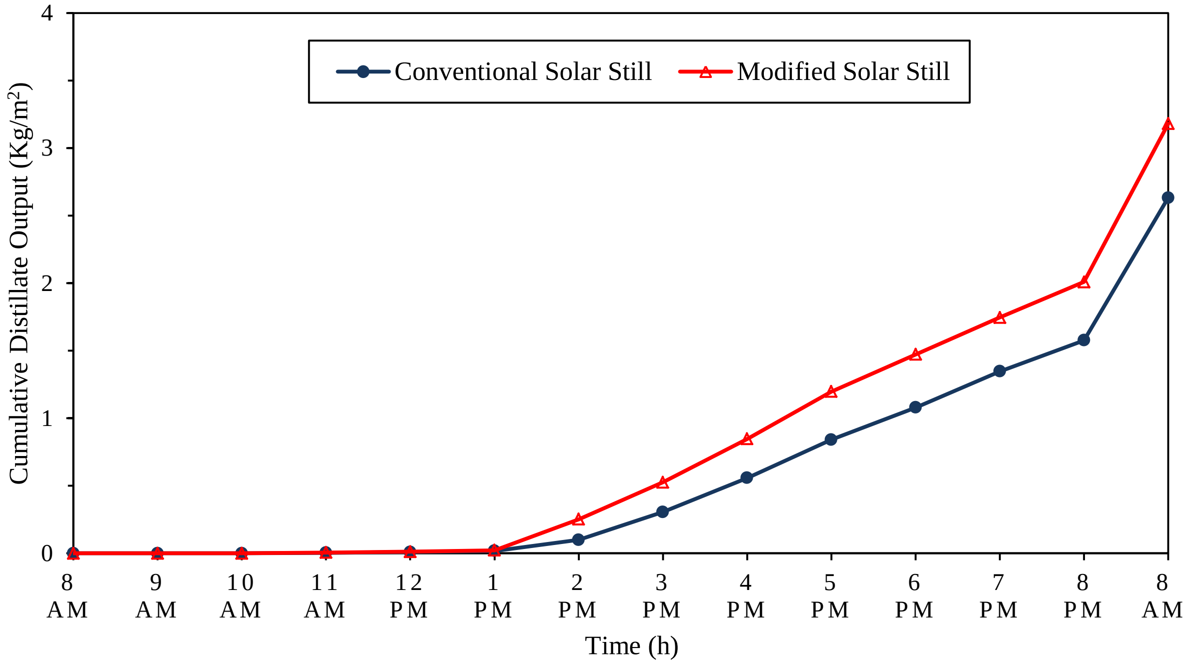

Figure 4.6 Variation of cumulative distillate output of conventional still and modified still

4.1.3 Stills having Basin water depth of 5 cm

Experiment was performed on 27th April 2018. At the beginning of this experiment, basin of both the stills, i.e. conventional and modified stills were filled with 5 cm water depth. The hourly variation of ambient temperature and solar radiation intensity is shown in figure 4.7. The maximum solar intensity was 812 W/m^2 at 1 PM while maximum ambient temperature was 41.1 ^0C at 4 PM.

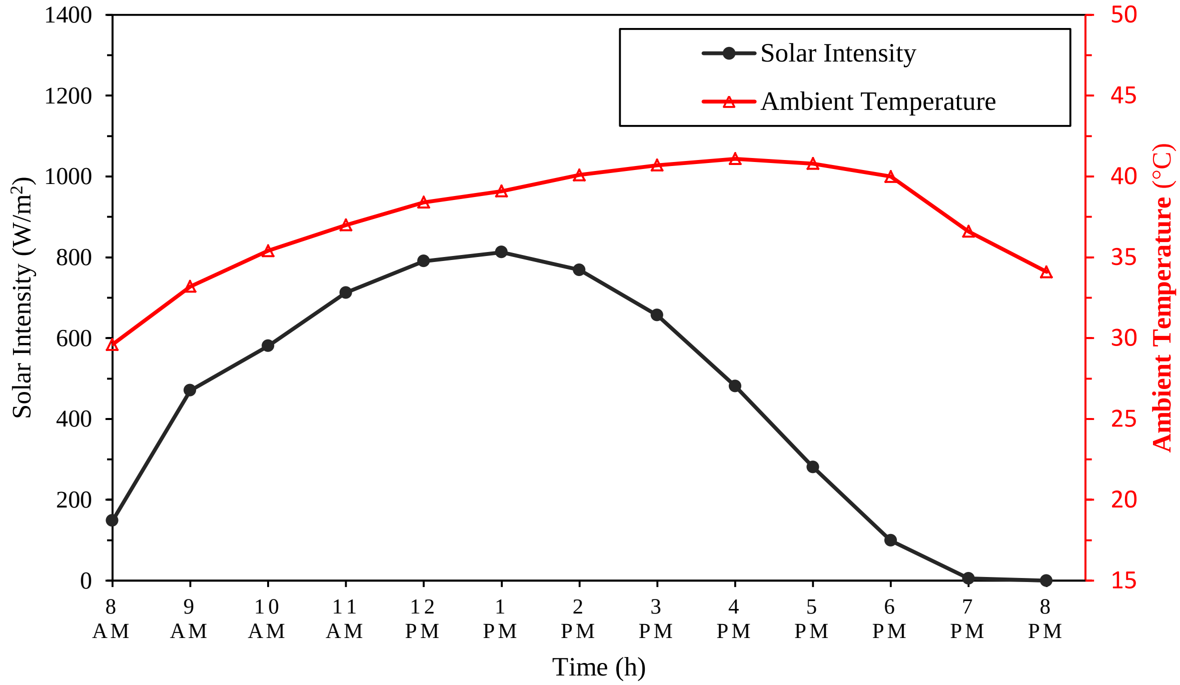

Figure 4.7 Variation of ambient temperature and solar intensity on 27 April 2018

The variation of basin water temperature of modified still, conventional still, shallow solar pond and mini pond for the 24 hour period is shown in figure 4.8. The basin water temperature of MSS remains high as compared to that of CSS throughout the day. The basin water temperature of MSS and CSS rises till 3 pm. The maximum basin water temperature of MSS was 66.1 ^{0}C while that for CSS was 64 ^{0}C. The maximum basin water temperature of SSP was 78.2 ^{0}C at 3 pm.

The variation of cumulative distillate output of MSS and CSS is shown in figure 4.9. It can be noticed that cumulative distillate output of MSS is greater than that of CSS. The distillate output of CSS and MSS for 24 hour was 2.69 kg/m^2 and 3.08 kg/m^2 respectively. The increse in productivity was 14.5 % as compared to CSS.

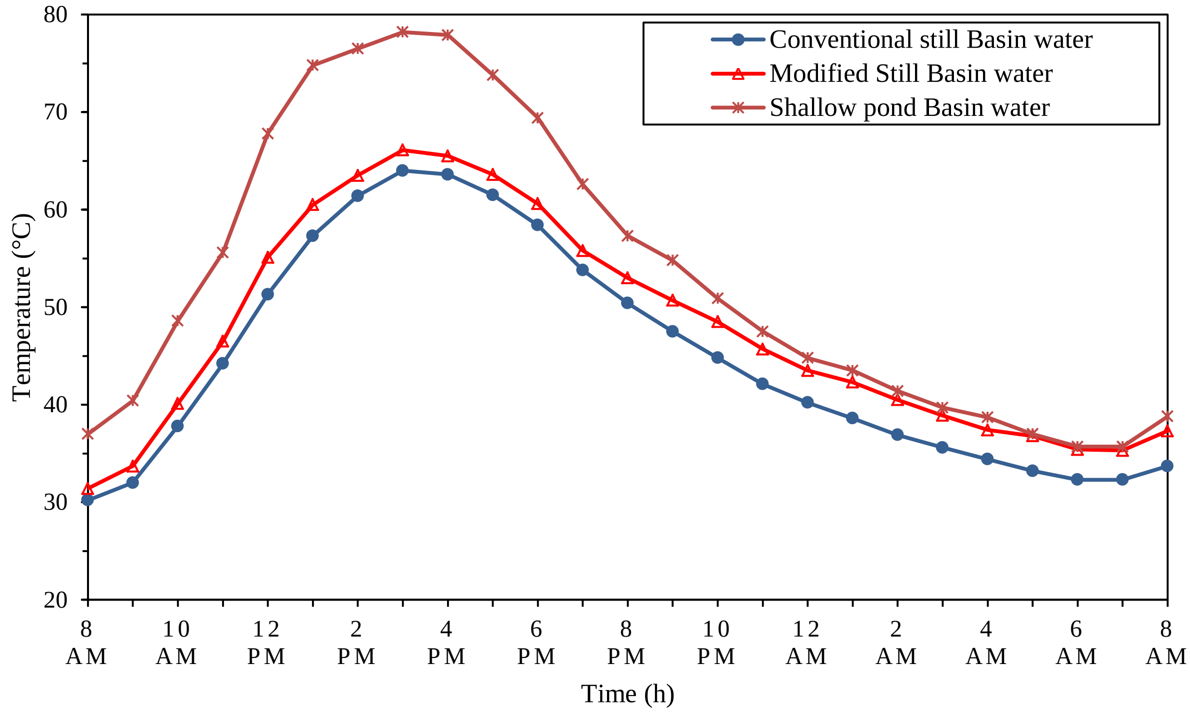

Figure 4.8 variation of basin water temperature of modified still, conventional still and shallow pond

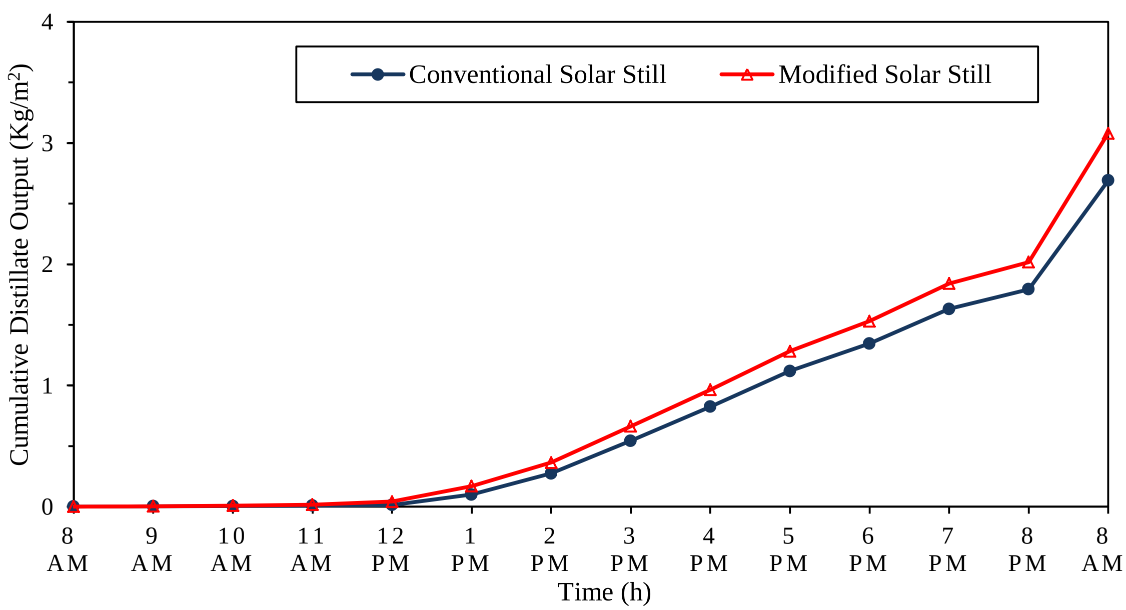

Figure 4.9 Variation of cumulative distillate output of conventional still and modified still

4.1.4 Productivity gain at different basin water depth

The overall productivity gain of MSS coupled with SSP compared to CSS at different depth of basin water in still is shown in Figure 4.10. The maximum gain in productivity of MSS was 20.85 % at still basin water depth of 6 cm as compared to CSS.

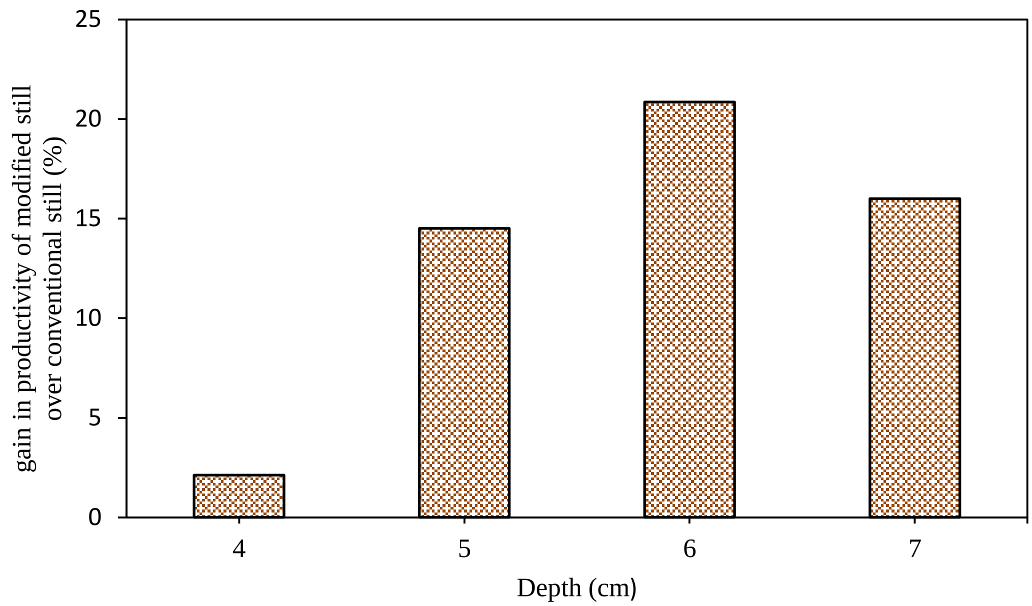

Figure 4.10 Productivity gain of modified still over conventional still at different basin water depth

4.2 TEST RESULTS OF CASE 2: Modified solar still (still coupled with mini pond and shallow pond) having basin water depth of 6 cm

In this study MSS is coupled with a SSP and MSP. Additional heat is supplied to the MSS from SSP for the initial period of 12 hours (8 AM to 8 PM). MSP was used for supplying energy to the MSS during night only. Additional heat is supplied from MSP to MSS from 12 AM to 2 AM and 4 AM to 6 AM. Experiment was performed on 26^{th} May 2018. At the beginning of this experiment, basin of both the stills, i.e. CSS and MSS were filled with water at depth of 6 cm. The depth and volume of water in SSP was 2 cm and 25.8 litre respectively. The volume of water in MSP was 600 litre.

The variation of ambient temperature and solar intensity on 26 May, 2018 is shown in figure 4.11. The maximum solar intensity was 986.214 W/m^2 at 1 PM while maximum ambient temperature was 47.7 ^{0}C at 2 PM.

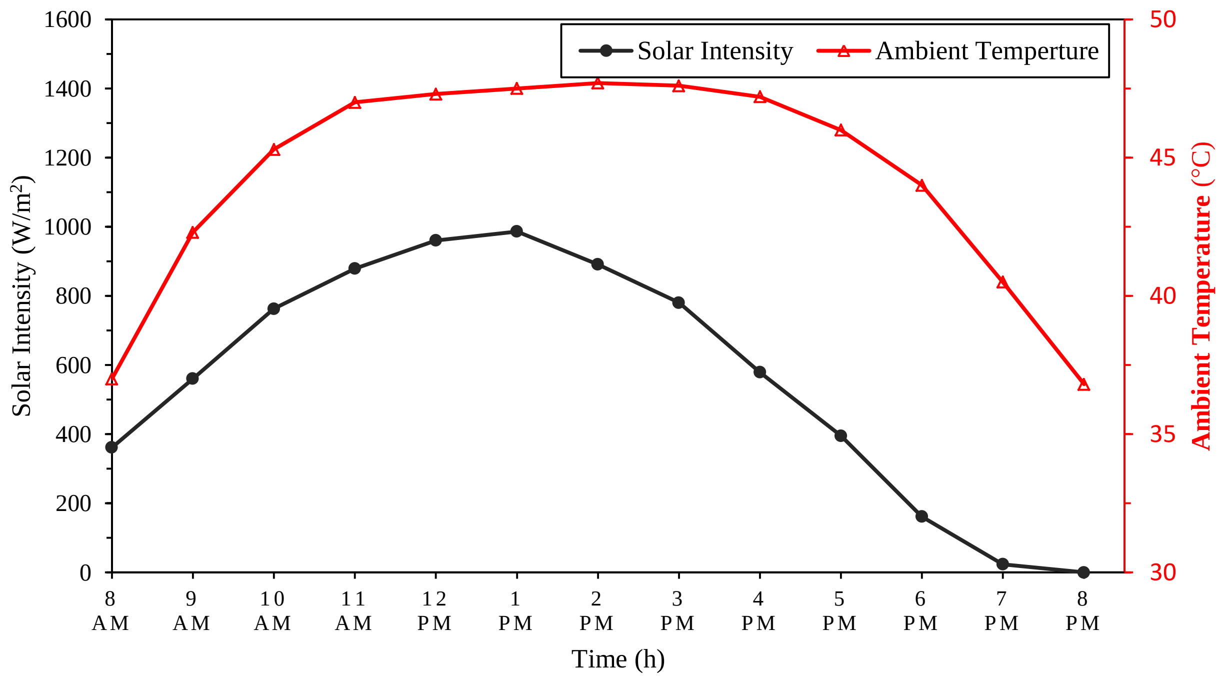

Figure 4.11 Variation of ambient temperature and solar intensity on 26 May 2018

The variation of basin water temperature of MSS, CSS, MSP and SSP for 24 hour period is shown in figure 4.12. The basin water temperature of MSS remains high as compared to that of CSS throughout the day, because of the additional heat supply from SSP to MSS during 8 am to 8 pm. The basin water temperature of MSS and CSS rises till 3 pm, due to high solar intensity. The max basin water temperature of MSS was 73.8 ^{0}C while that for CSS was 68.6 ^{0}C.

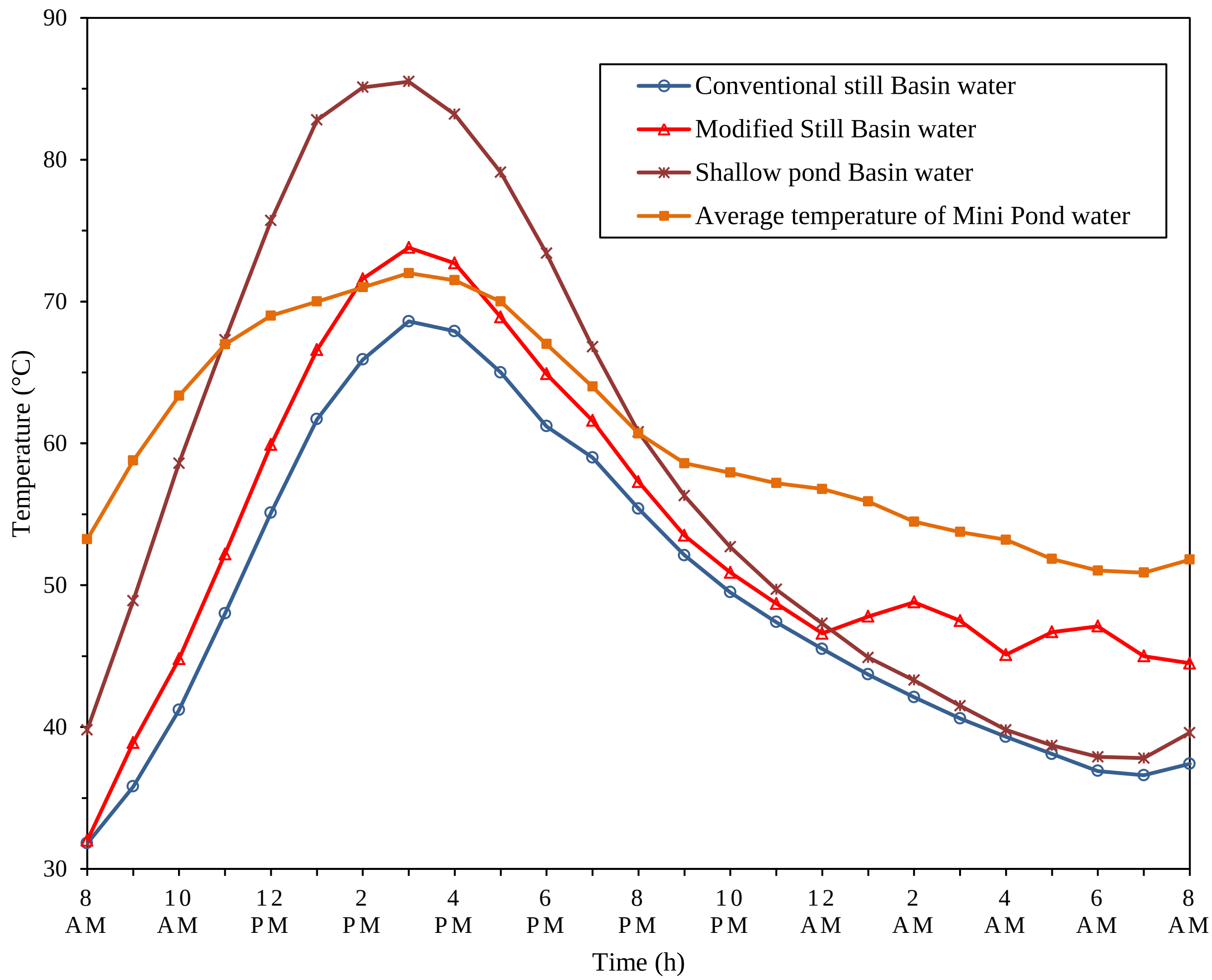

Figure 4.12 Variation of basin water temperature of Conventional still, modified still, mini pond and shallow pond

The basin water temperature of SSP rises till afternoon. Its maximum basin water temperature was 85.5 ^{0}C at 3 pm. There is sharp rise in basin water temperature from 8 am to 1 pm, due to the rise in solar intensity in afternoon. After 3 pm its temperature begins to fall, due to decrease in solar intensity and heat loss from upper glass cover along with side walls. The average water temperature of MSP increases from 8 am to 3 pm, after that it starts decreasing, due to decrease in solar intensity and heat loss from the side walls along with transparent glass cover.

There is sharp rise in basin water temperature of MSS during 12 am – 2 am and 4 am – 6 am, due to an extra heat supply from MSP in closed cycle during this period. There is sharp decrease in temperature of MSP during this duration of heat transfer. The variation of cumulative distillate output of MSS and CSS is shown in figure 4.13. The cumulative distillate output of MSS is greater than CSS. The distillate output of CSS and MSS for 24 hour was 3.20 kg/m^2 and 4.6 kg/m^2 respectively. The increse in productivity was 43.75% as compared to CSS.

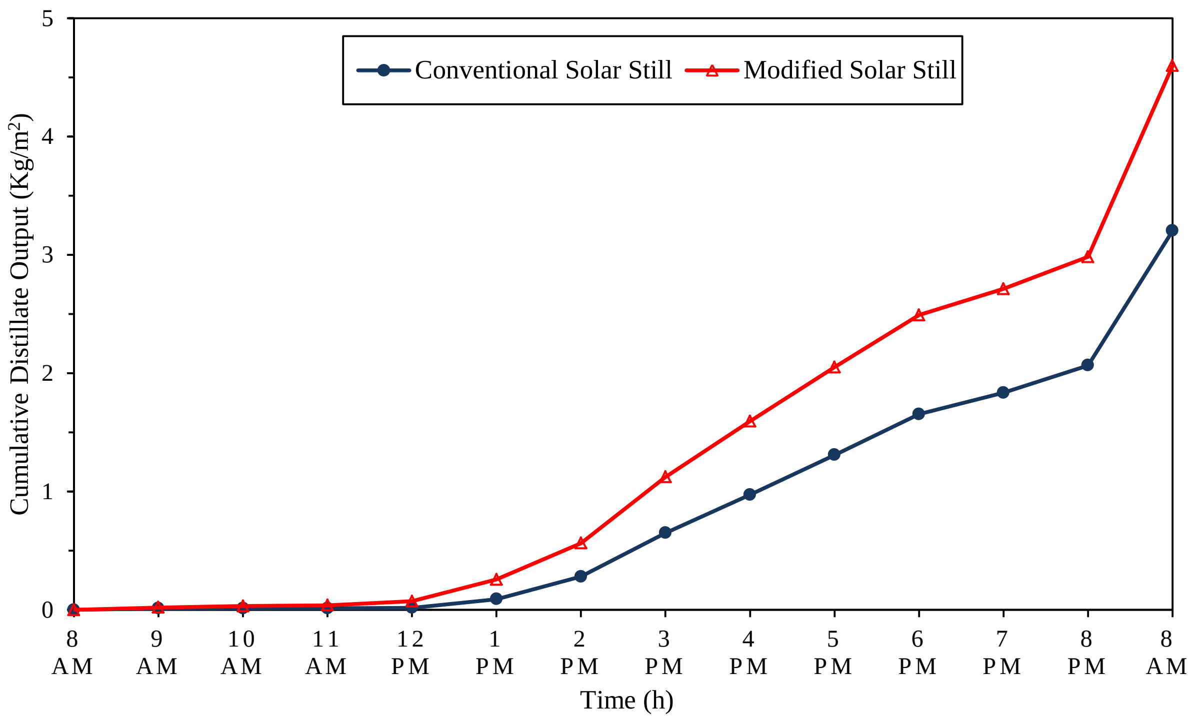

Figure 4.13 Variation of cumulative distillate output of conventional still and modified still

Chapter 5

CONCLUSIONS & FUTURE SCOPE

5.1 CONCLUSIONS

In this study, performance of modified single slope basin type still coupled with mini pond and shallow solar pond as external heat source has been examined. The productivity of modified solar over reference still, by varying the basin water depth was studied. On the basis of experimental results, the following conclusions can be drawn:

- The temperature of the basin water of solar still coupled to a shallow solar pond remains higher throughout the day as compared to the temperature of the basin water of conventional solar still. Due to this, the daily productivity of solar still coupled with a shallow solar pond remains higher as compared to its conventional counterpart.
- The performance of solar still integrated with shallow solar pond is examined by varying the basin water depth of the still. The gain in the daily productivity of modified still having basin water depth of 5 cm, 6 cm, 7 cm was 14.5%, 20.85%, 16% respectively.
- The total cumulative distillate output of modified still having basin water depth of 6 cm and coupled to a SSP was found to be 3.18 kg/m^2-day.
- The gain in the daily productivity of the modified solar still coupled with shallow solar pond and mini pond was found to be 43.75% over conventional solar still.

5.2 FUTURE SCOPE

Following are the recommendation for future work:

- In the present work, shallow solar pond was used to supply heat to the basin of modified solar still in continuous cycle mode. However, in future work, it could be supplied in batch cycle mode with an optimum frequency.
- Research could be carried out to construct solar still designs having low initial cost and maintenance by incorporating a method that can increase the intensity of solar radiations falling on still without using solar tracking mechanism, which is very costly in present days.

- Research could be conducted for various mass flow rate of heat exchanger of shallow solar pond and mini pond.
- In the present work, the performance of solar still has been studied by connecting it with mini solar pond and shallow solar pond. However, in future work, internal condenser could be added to the given combination.

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