An Experimental Investigation of Basin Type Single Slope Solar Still having Multiple Floating Wicks in the Basin

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CERTIFICATE

I, **Himanshu**, declare that this thesis report entitled, "**An Experimental Investigation of Basin Type Single Slope Solar Still having Multiple Floating Wicks in the Basin**" submitted towards fulfillment of the requirements for the award of Master's Degree in Thermal Engineering, in Mechanical Engineering Department of Thapar University, Patiala, is entirely my own work. This document has not been submitted for any degree in any other institution.

Himanshu

Date: **7th July, 2017**

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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Dedicated to

My parents

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Abstract

In present time, the amount of fresh drinkable water is decreasing due to contamination of water from industrialization and urbanization. In coastal regions and arid areas, abundant amount of sea water or slightly saline water is available but there is scarcity of potable water. The most economical method to overcome this scarcity of water is use of solar still, which converts brackish water into potable one without using any conventional source of energy. The main drawback associated with solar stills is their low productivity. In the present work, a single slope basin type solar still has been modified by placing multiple float wicks in the basin of the still. The float wick was made by wrapping black cotton cloth on thermocol sheet having protective layer of polyurethane foam to avoid any burn out due to high temperature. The basin area of the still was 1.15 m^2 and transparent glass cover of 5 mm thickness was inclined at an angle nearly equal to latitude of Patiala. The performance of modified still has been compared with the conventional basin type still of identical specifications under same ambient conditions. The effects of covering basin area of the still with float wick in different proportions and varying basin water depths on the productivity of still have been investigated. The use of float wicks reduced thermal inertia of the basin leading to early response and higher operating temperatures which resulted in enhanced distillate outputs of the modified still as compared to the conventional still. The modified still performed better, when basin area of the still was partially covered with float wick because of availability of path for heat transfer between warm basin water and top surface of wick during night, which was hindered in the case when complete evaporating surface area was covered with float wick. The highest overall daily productivity gain of 20.56% was achieved for modified still over the conventional still when 75% area of the basin was covered with float wick at basin water depth of 5 cm. The effect of varying basin water depth on the productivity of the modified still was negligible; hence, modified still can also be operated at higher basin water depths.

Keywords: Solar still, Single slope, Floating wick

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Chapter 1

Introduction

1.1 Introduction:

Water demand for domestic, agricultural and industrial purposes has increased considerably these days. Two-third part of the surface of the earth is covered with water. 97% of the total available water is salty and only 3% is fresh which is fit for drinking [1]. This available small fraction is not enough to meet the daily demand which has increased day by day in twenty first century due to higher growth rate in population and industries.

In coastal regions and arid areas where sea water or slightly salty water is available but there is scarcity of potable water. There are many ways to treat this impure water by using conventional energy. But in remote areas where conventional energy is costly or not available, the solar distillation is the main technique that can be utilized to get consumable water [1]. It is also coincidence that, in times of high water demand, solar radiations are also very intense. In solar distillation, heat energy is given as input which is taken from the sun. Solar stills are very cheap devices which can be used in solar desalination technology. The main advantage of using solar still is that it makes use of clean and free energy due to which this device is eco-friendly.

Solar distillation has been first utilized by ancient Greek mariners and alchemists. Other scientists and naturalists such as Della Porta, Lavoisier and Manchot used solar stills over coming centuries. The first conventional solar still plant was constructed by Charles Wilson, a Swedish engineer in Las Salinas. This was basin type still used for supplying fresh water to a nitrate mining community. The distillate output of the plant was 4.9 kg per square meter on sunny day [2] . The US government established Office of Saline Water to manage funds for development in the field of solar distillation projects. The performances of various configurations of solar still were studied in one of the five demonstration plants built by Office of Saline Water at Daytona beach in Florida. Solar distillation program came into existence at Melbourne facilities of Commonwealth Scientific and Industrial Research Organization in Australia[3].

1.2 Working of Solar Still:

Conventional basin type solar stills either single or double sloped can be easily made by unskilled labor as their construction is very simple. The working of solar still is based on principle of rain water i.e. evaporation and condensation. As water from oceans evaporates, it condenses and returns to earth in the form of rain. When the water evaporates, it leaves all contaminations behind it. Solar stills make use of this natural process.

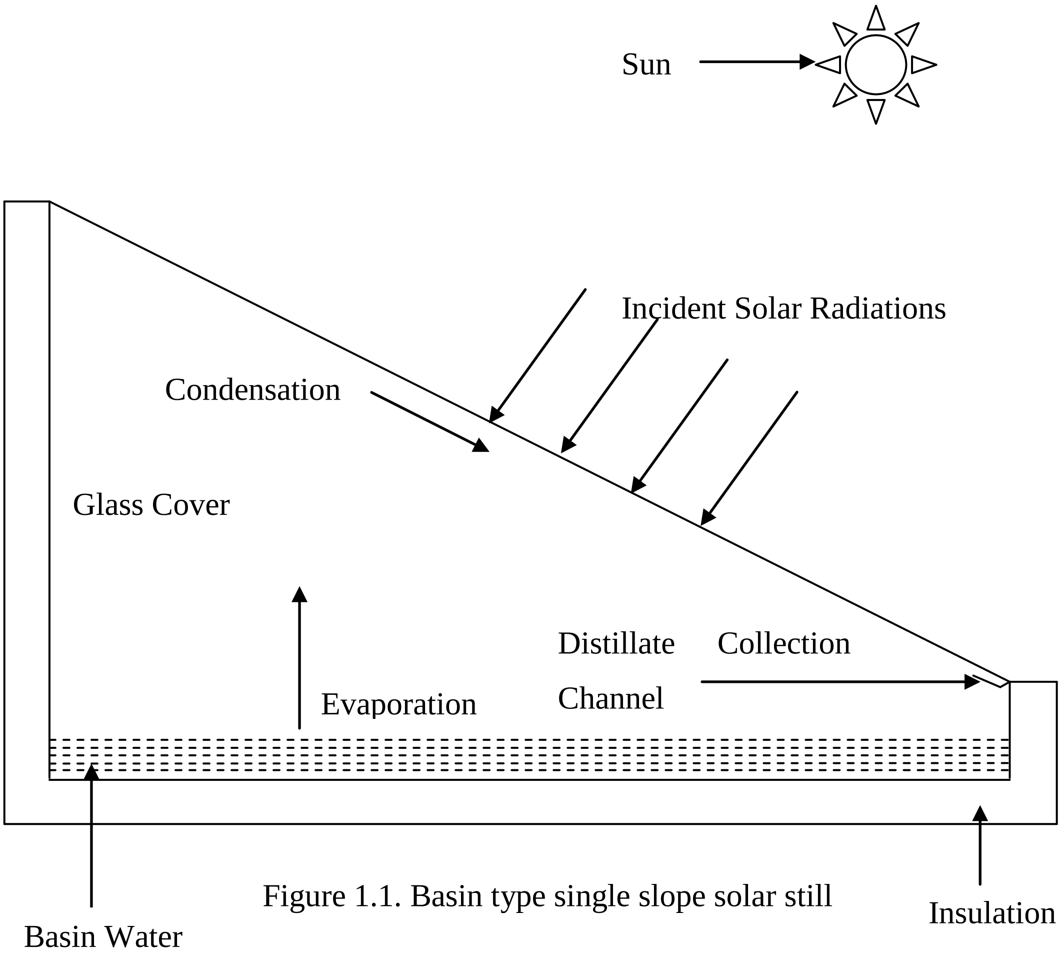

Figure 1.1. Basin type single slope solar still

A solar still has a top cover made of glass or plastic which allows rays of sun to transmit through it. The interior surface is made up of waterproof membrane which is also called basin and uses blackened material to improve absorption of sunlight. As beams of sun fall on the still, the water starts to warm up and moisture percentage of air trapped between top layer of basin water and glass cover enhances. The heated water vapors evaporate from basin and condense on the inner side of the transparent glass cover. This condensed water which is free from impurities is collected in the container by action of gravitational force. In this way we can get pure water from brackish water with the help of solar energy which is available in abundant without consuming any energy source which is available in limited quantity to us [4].

1.3 Classification of Solar Stills:

Solar stills can be classified as-:

1.3.1 Single slope solar still:-

It has single glass cover over which condensate is collected. The main components of single slope solar still are basin, transparent cover, condensate channel, sealant, insulation, basin liner, supply and delivery system. The cover of the solar still should have high transmittance for solar radiations, light weight, long life. The basin liner should be able to withstand high temperature and sealant should remain resilient at very low temperature [5].

1.3.2 Double slope solar still:-

The operation of this solar still is similar to that of single slope solar still but it has two glass covers that increase condensing area for condensation of rising vapors inside the still [5].

1.3.3 Tubular solar still:-

In this type of still, the construction includes transparent tubular glass cover with plastic lids at both ends and a semi-circular black trough. As compared to single & double sloped stills, more radiations can be absorbed due to curved shape of tubular glass cover and also there is not any need of tracking system [5].

1.3.4 Multi effect solar still:-

The latent heat of vapor condensation is dissipated to atmosphere in conventional solar still. In multi effect solar stills, the heat liberated by lower glass cover when warm basin water is converted into vapors serves as additional heat source for upper basin in place of being released to ambience. Additional basin must be consisted of transparent material so that radiations can be reached at lower basin [5].

1.3.5 Cascade solar still:-

These are identical to that of basin type solar stills but difference is that internal absorber plates are built up of various steps and trays on horizontal side. The glass and top basin water layer temperatures of cascade stills are higher than that of basin type which brings about higher evaporation and condensation rate [5].

1.3.6 Stepped solar still:-

In this still, stepped tray type basin along with conventional basin is provided to increase evaporation rate [6].

1.3.7 Wick type solar still:-

The rays of sun transmitted through glass cover reaches the wick surface where it is absorbed in this type of still. Some of the energy is used for heating water streaming through wick because of capillary action. Water flowing through wick gets converted into vapors and condenses on lower surface of glass cover [7].

1.4 Parameters affecting solar still productivity:

The productivity of basin type solar still depends mainly on three factors which are climatic conditions, operating and design conditions as shown in Figure 1.2.

1.4.1 Climatic conditions:

These include solar radiation, wind speed, ambient temperature, dust and cloud cover. These parameters cannot be controlled as they are metrological factors.

Solar radiation:- Many experiments have been conducted to study the effect of solar radiations on still and demonstrated that the distillate output of the solar still enhances as intensity of radiations falling on the still increases. It is because of the fact that the increase of energy transfer rate increases yields [8].

Wind speed:- An experimental study revealed that yield of solar still increases with the wind speed only below critical speed of 4.5m/s, after which it remains constant. It is due to fact that the heat transfer from cover and thus condensation increases up to critical speed, beyond which there is not any significant increment [8].

Ambient temperature:- Many researchers have studied effect of variation in ambient temperature on solar still. The results showed that very small increase in productivity in the order of 3% was possible by rise in an ambient temperature of 5^0C [8].

Dust and cloud cover:- When dust is accumulated on the glass cover, its transmittance decreases which results in loss of the incident solar radiations .The experimental results proved that the performance of still is better during mean cloud days than monthly general days [8].

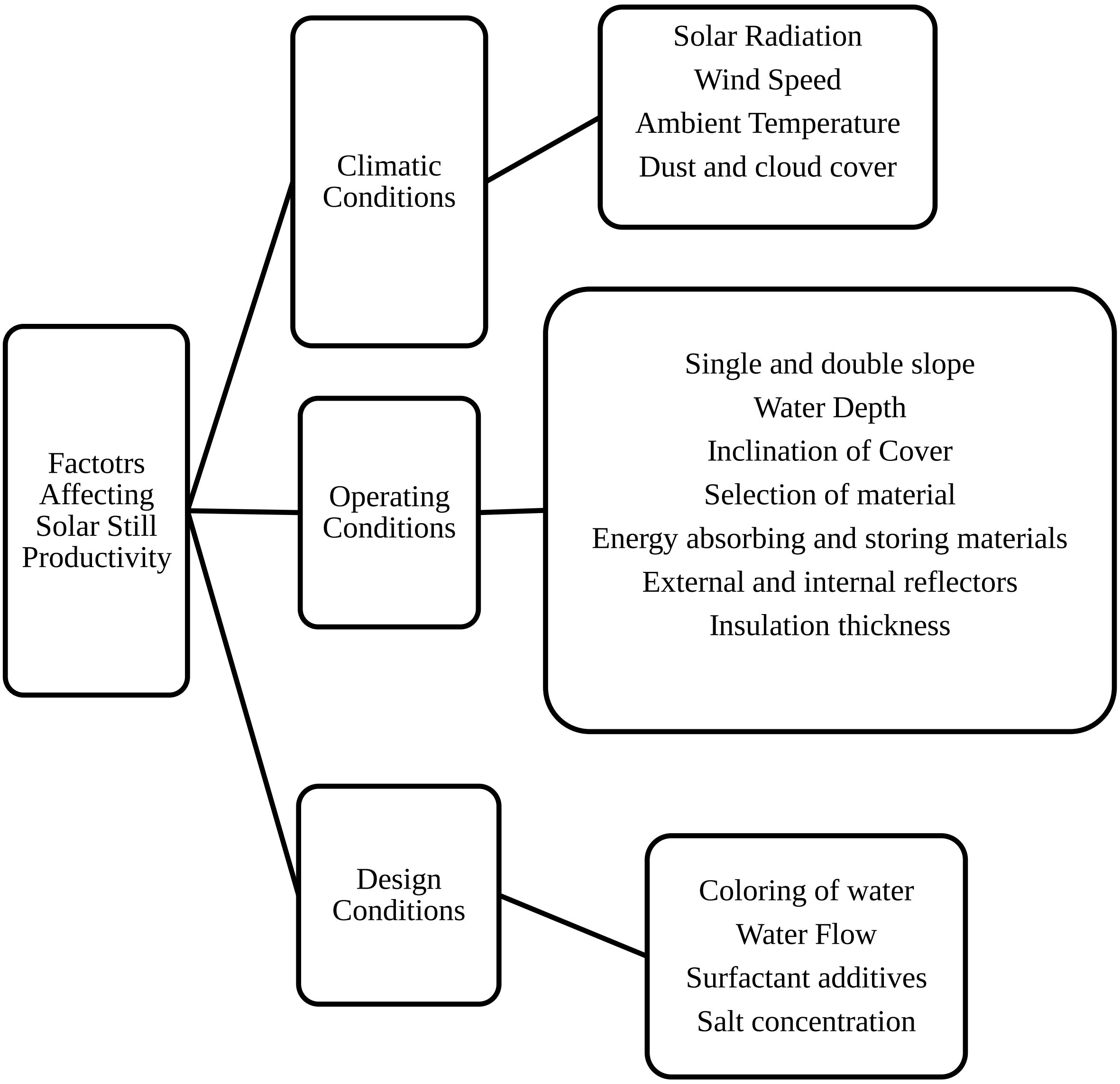

Figure 1.2. Factors affecting solar still productivity

1.4.2 Design parameters:

The productivity of the solar still can be increased by changing its design conditions

Single and double sloped solar stills:- Single sloped stills receive higher levels of solar radiations at both low and high altitude stations. It was experimentally discovered that addition of the extra basin in double sloped stills can increase its production significantly [9].

Inclination of cover:- The productivity of the solar still heavily depends on the inclination angle of the glass cover which in turn relies on the direction the cover is facing and also latitude of the place where still is installed. It is expected that if glass cover is aligned with latitude angle then it will receive solar radiations normally [9].

Selection of material:- The cover material of still can be glass or plastic. Glass is preferred because of its high transmittance but plastics are cheaper. The experimental results proved that the productivity of the still with 3 mm thick glass cover is higher than that of the still with 6 mm glass thickness. The basin liner material should be leakage proof and also capable of absorbing solar radiations. It should able to withstand high temperature. Most commonly used basin materials are asphalt mats, rubber and polyethylene sheets. Transparent cover should be properly sealed to avoid vapor leakage. Silicon is the most effective sealant while others are tars, tapes etc [9].

Energy absorption and storing materials:- The incident solar radiations can be increased by increasing the absorptivity of the solar still. The addition of several materials to the basin results in enhancement of absorptivity and thus reduces losses. Material used can be sensible heat storage such as charcoal, black rocks etc. or latent heat storage such as phase changing materials (paraffin, stearic acid etc.) [9].

External and internal reflectors:- It is experimentally concluded that addition of reflectors to solar still can increase the distillate output significantly [9].

Insulation thickness:- The thickness of insulation plays very important role to a point in solar still. It is due to increase in operating temperature because of insulation. According to Khalifa and Hamood 60 mm thick insulation increased the output to 80% [9].

Water depth:- The performance of the solar still is strongly influenced by the water depth in the basin. It has been found that the maximum distillate output is achieved with minimum water depths. But it is very tough to retain least water depths in the still because dry spots can appear at minimum depth [10].

1.4.3 Operational parameters:

These include coloring of water, water flow, surface additives, salt concentration etc.

Coloring of water:- In conventional still, the base absorbs large amount of heat due to which it becomes the hottest area of the still. Heat is transferred from bottom surface to water through convection and to surroundings via conduction through insulation. Addition of dye in water will allow the still to absorb all solar radiations and then water will convect heat to base of the still from where it will be conducted through insulating material. So the productivity of solar still increases because of its mixing with the die [11].

Water flow:- The distillate output of a still strongly relies on temperature difference between water and glass cover. It is proved that heat transfer coefficient and yield are directly proportional to each other. The experimental results indicated that performance of still with water flow over glass cover was superior to that of the conventional still [11].

Surfacant additives:- Addition of surfactants to water lowers surface tension and hence enhance evaporation rate. Therefore distillate output of the still can be enhanced by adding surfactants [11].

Salt concentration:- Salt concentration is inversely proportional to distillate output of still. Increase in salinity of water results in decrease in distillate output [11].

In the present study, the conventional basin type single slope solar still has been modified by placing multiple float wicks in the basin and referred as modified still in the present study. The performance of modified still has been compared with the conventional basin type still of same material and dimensions. The effect of covering basin area of the still with float wick in different proportions has been investigated. The experiments have also been performed to study the effect of varying basin water depths.

1.5 Research Objectives

An experimental work has been carried out to investigate the performance of modified basin type single slope solar still with the following objectives.

- To investigate the effect of floating wicks on productivity of modified still.
- To determine the performance of modified still by covering the basin water surface with float wicks in different proportions.
- To compare the performance of modified still with that of conventional still.
- To study the effect of basin water depths on productivity of modified still.

Chapter 2

Literature review

Numerous researchers have carried out a lot of research to study the various parameters affecting the performance of the solar stills. This section reviews the previously published literatures on the solar stills. It permits better understanding of the topic and also acts as foundation for the present work. This chapter deals with literature reviews on the various modifications such as use of different energy storage materials, wick materials applied on the solar stills to improve their performance.

Sebaii et al. [12] theoretically and experimentally analyzed the performance of single basin single slope solar still having movable baffle suspended absorber with vents in the basin. The basin area and angle of inclination of the glass cover of the still were 1.035 m^2 and 15^0 respectively. The bottom and sides of the solar still were insulated with the help of layer of saw dust of thickness 0.075 m to prevent the heat losses. The absorber was used to lower the time taken by the basin water for preheating. The vents provided on the absorber plate divided the basin into two portions. The absorber plate was able to move up and down, due to which ratio of masses of water in upper and lower columns can be changed. During night, the mass of water kept below the absorber plate acted as heat source for the mass of water above the plate. It was observed that the upper surface temperature of basin water was higher in modified still than that of the conventional still. The hourly distillate output of solar still with baffle suspended absorber was higher than that of the simple basin type still during day time. The experimental results showed 20% increment in the daily productivity of the still having baffle suspended absorber over the conventional still. The distillate output of the still was found to decrease with increase in vent area.

Nafey et al. [13] investigated performance of single slope basin type solar still to study the effect of parameters namely gravel size and rubber thickness under the similar ambient conditions. Four solar still units of identical dimensions, each having basin area of 0.25 m^2 and 15^0 inclination angle of the glass cover were constructed. The inner sides of the basin were painted white, so that sides of the still throw radiations into basin water without absorbing it. The heat losses from bottom and sides of the solar still were prevented by providing insulation with foam. The effect of varying thickness of rubber on the distillate output of still was investigated by using three pieces of rubber having different thicknesses. The experiments were performed to study the effect of gravel size on productivity of the still. It was observed that the distillate output of the still increased as volume of water in the basin was increased at same rubber thickness. The black rubber of 10 mm thickness resulted in enhancement of distillate output by 20% at brine volume of 60 l/m^2. It was revealed that the gravels with size 20-30 mm increased the productivity of the still by 19% for 20 l of saline water in 1 m^2 area of the basin. The experimental results indicated that the black gravels absorbed and released incident energy in less time than that of black rubber.

Arabi et al. [14] analyzed the performance of basin type solar still with water flowing between two glass covers. The area of the basin of the still was 1 m^2. The purpose of water flowing between two glass covers was to reduce glass temperature which resulted in increment in temperature difference of glass and water. Thus, productivity of the still was improved due to increased rate of evaporation in the basin of the still. The performance of the modified still was compared with conventional basin type still of identical dimensions under similar ambient conditions. It was observed that the performance of stills was strongly influenced by extent of insulation used. The experimental results indicated that the double glass still performed better than the conventional still when heat losses from the basin of the still exceeded beyond a certain limit. But for perfectly insulated stills, the conventional solar still gave higher yield. It was concluded that the effects of flow rate of cooling water and glass spacing on distillate output of the still was negligible.

Hijleh et al. [15] conducted various experiments to compare the performance of basin type solar still having sponge cubes of different sizes in the basin with another conventional still of similar dimensions in same ambient conditions The solar still having basin area of 0.25 m^2 with 23^0 inclination angle of the glass cover was constructed. The use of sponge cubes resulted in decrease in surface tension of molecules of water and thus increased the evaporation rate. . All the results were discussed in terms of production ratio which is the ratio of distillate output of the still having sponge cubes to that of the conventional still. The experimental results indicated that the production ratio was strongly influenced by depth of water in the basin. The production ratio varied as size of sponges used in the basin was changed. The evaporation rate was decreased because of reduced wetted area while using large sized sponge, but on the other hand higher temperature of top surface of sponge increased the evaporation rate. So it was concluded that variation in production ratio as function of sponge size was net effect of these contradicting effects. It was found that the sponge cubes in the basin caused appreciable increment in the productivity of the still up to 273%. The best results were obtained for sponge cubes of size 6 cm at the basin water depth of 7 cm. It was also observed that the use of sponge cubes was less effective for the higher salinity of the basin water.

Nijmeh et al. [16] theoretically and experimentally analyzed the performance of basin type double sloped solar still having various energy absorbing materials. The material selected for construction of basin was stainless steel. The inclination angle of the glass cover and the basin area of the still were 35^0 and 3 m^2 respectively. The heat losses from bottom and sides of the still were prevented by using Styrofoam insulation of 10 cm thickness. The total global radiations on both glass surfaces and horizontal surface were recorded by using three different pyranometers. The materials used to increase the distillate output were dissolved salts, charcoal and violet dye. Higher basin water temperatures were observed while using violet dye as energy storage material in the basin of the still. The experiments were conducted to study the effect of covering surface area of the still with charcoal in different proportions. The addition of potassium dichromate and potassium permanganate resulted in increase in efficiency of still by 17% and 26% respectively. The best material used to enhance the efficiency was violet dye. It was revealed that the optimum efficiency and productivity were achieved with charcoal, when it covers 50% of the basin surface area. The efficiency of still decreased as proportion of basin area covered with charcoal increased because of reduced evaporation area resulted from charcoal floatation.

Tiwari et al. [17] conducted various experiments to study the effect of basin water depth on heat transfer coefficient in single slope solar still. The still having basin area of 1 $m^2$was made up of glass reinforced plastic. The glass cover of the still was sloped at an angle of 30^0. The bottom surface basin of the still was blackened to enhance the absorption of solar radiations. The glass cover of the still was fastened with iron frames and rubber gasket was placed between cover and frame to prevent leakage of vapors. The temperatures at different locations of still were recorded with the help of copper constantan thermocouples. The convective heat transfer coefficients were found at five different depths of water. It was observed that the changes in water temperature were lesser with increased depth of water in the basin of the still due to effect of stored energy at higher depths. The experimental results demonstrated that time taken by basin water to exceed glass cover temperature was enhanced with increased water depths. The highest distillate outputs were obtained at lower water depths. The study indicated that the internal heat transfer coefficients were strongly influenced by depth of water in the basin of the solar still. It was also concluded that appreciable amount of distillate was obtained at higher depths of water during night.

Phadatare et al. [18] conducted experiments on single basin single sloped plastic solar still having basin area 1.446 m^2. The cover of the still was made up of Plexiglas and sloped at an angle of 20^0. The bottom and sides of the solar still were insulated with the help of layer of glass wool of thickness 2.5 cm to reduce the heat losses from basin of the still. Silicon rubber was used as sealant to prevent any leakage of vapors from basin to atmosphere. It was observed that the basin water temperature first decreased with increased water depths but at higher depths there was negligible change in basin water temperature by varying depth of water in the basin of the still. The maximum productivity of 2.1 l/m^2/day was obtained for water depth of 2 cm in the basin. It was observed that the efficiency of still varied from 10% to 34% and maximum efficiency was achieved at depth of 2 cm. The results of the experiment showed that the cover temperature exceeded the basin water temperature when solar intensity was more than 550 W/m^2, if still was built up of Plexiglas. The results showed that the radiative heat transfer coefficient was more than the convective, and the evaporative heat transfer coefficient was highest.

Badran [19] did experiments on single slope basin type solar still having asphalt basin liner and sprinkles in the basin. The basin area of the still was 1 m^2 and slope of 4 mm thick glass cover was 32^0. Silicon rubber was placed between glass cover and frame of the still to avoid any leakage of vapor to atmosphere. The insulation was provided with 5 cm thick layer of rock wool to minimize the heat losses. Mirrors were fastened on the interior side walls of the still to reflect the solar radiations in the basin water. The temperatures of the different elements of the still were recorded with the help of K-type thermocouples. Solar radiations were measured by using heliometer. The study demonstrated that the maximum distillate output was achieved during 1:30 PM and 2:30 PM. The results of the experiments showed that the use of asphalt basin liner resulted in 29% improvement in the still production. The combination of asphalt basin liner with sprinklers was more prominent than the application of asphalt alone and resulted in further 22% increase in distillate output of the still. It was also observed that the productivity of the still was directly influenced by wind and ambient temperature. The results also proved that the yield from the solar still can be enhanced by decreasing the depth of water in the basin of the still due to lowered heat capacity of the basin water.

Samee et al. [20] analyzed the performance of basin type solar still having area of 0.54 m2. The glass cover of the still was inclined at an angle of 33.30. The heat losses from sides and base of the solar still were prevented by providing insulation of Styrofoam sheet of 3 cm thickness. The basin of the still was blackened to enhance the absorption of solar radiations. The daily productivity of the still was calculated as 1.7 l/day depending on the data of 8 days. The efficiency of the still was found to be 30.65% with highest distillate output of 0.339 l/hr at 1 PM. The thermo physical and chemical properties such as conductivity, pH and total dissolved solids of different samples of water before and after desalination were also measured. The values of total dissolved salts, conductivity and pH of surface water after desalination were 30 ppm, 41 µS/cm and 5.74 whereas before desalination these were 370 ppm, 1.291 µS/cm and 6.72 respectively. The total cost for construction of still was estimated to be Rs. 6040.

Murugavel et al. [21] investigated the performance of double sloped basin type solar still modified by using various materials such as cotton cloth, jute cloth, sponge and porous materials namely quartzite rocks and washed stones. The still having effective basin area of 1.74 m^2 was consisted of mild steel and glass cover was sloped at an angle of 30^0. The maximum value of hourly distillate output was obtained when cotton cloth was placed in the basin of the still among all materials. The cumulative productivity was lesser during heating, whereas it was higher during cooling while using quartzite rocks in the basin. The overall maximum cumulative productivity was achieved with light cotton cloth kept in the basin of the still. The rate of rise basin water temperature was higher for still having light cotton cloth due to which distillate outputs from this still were enhanced. It was also observed that the higher distillate outputs were obtained for the still with lower water temperatures, during the interval of elevated basin water temperatures as in case of the still having light cotton cloth in the basin of the still. The experimental results indicated that the rate at which distillate output produced was dependent on various parameters such as heat capacity of the basin, glass and water temperature difference, glass and water temperatures.

Kumar et al. [22] carried out various experiments to study the performance of single slope basin type solar still having increased rate of condensation. The condensation occurred on the sidewalls of the basin of the still can be enhanced by circulating water through the tubes attached on the surface of walls. The basin area of the still was 0.5 m^2. The cover of the still was made up of glass and sloped at an angle of 15^0. The base and sides of the basin were insulated with the help of glass wool to minimize the heat losses. It was observed that the rate of evaporation was strongly influenced by wind speed, relative humidity, solar insolation and temperature etc. The rate of evaporation was found to be highest in the still having without surface cooling. The maximum distillate output of 1.4 l/m^2/day was obtained with daily efficiency of about 30%. The condensate quality was also tested and found to be comparable with rain water and mineral water.

Abdallah et al. [23] improved the performance of basin type solar still by incorporating modifications in the design of the still such as applying mirrors on the inner side walls, using stepped basin in place of simple basin, integration of stepped basin with solar tracking mechanism. The performance of solar still with stepped basin was better than conventional basin type still with and without mirrors because of increased surface area and reduced air volume due to which trapper air was heated faster. It was also observed that the maximum basin water temperature was achieved in the solar still having stepped absorber plate because of enhanced absorption of solar radiations. The variation of basin water temperature was narrower in case of still having stepped basin due to which distillate output in this still was increased because of higher temperatures maintained for long time than that of the conventional still. The cover of the still was made up of 4 mm thick glass and inclined at an angle of 32^0. The use of reflecting mirrors on the inner side of the still resulted in increment of 30% in the productivity of the still. Improvement of 180% in distillate output was reported by substituting stepped basin in place of flat basin in the conventional basin type still. Integration of stepped basin still with solar tracking mechanism gave maximum rise of 380% in the productivity.

Sebaii et al. [24] presented mathematical model for basin type single sloped solar still having phase changing material kept below the basin liner. The glass cover of the still was inclined at an angle of 22.76^0. The experimental results indicated that the day distillate output and efficiency of still increased with increase in basin liner thickness up to value of 0.003 m while daily productivity increased until value of basin liner thickness of 0.001 m, after which daily productivity becomes independent of thickness of basin liner. The results of the simulation showed that the phase changing material worked as source of heat for basin water after sunset. The daylight yield was found to reduce to small extent with increasing mass of phase changing material but nocturnal and daily distillate outputs were increased appreciably. It was revealed that the use of phase changing material was more prominent at lower depths of water in the basin during winter due to which it was suggested to incorporate energy storage materials in wick type solar stills. The daily distillate output on a summer day was found to be 9.005 kg/m^2/day with the daily efficiency of 85.3% while using stearic acid whereas it was 4.998 kg/m^2/day without phase changing material.

Sebaii et al. [25] analyzed the performance of single slopedbasin type active solar still using sand as heat storage medium by computer simulation. The angle of inclination and basin area of the still were 21.76^0 and 1 m^2 respectively. Temperatures of the various elements of the still were obtained from analytical expressions. The effect of different parameters such as mass flow rate and thickness of water flowing through still with different masses of sand on efficiency, day, nocturnal and total daily distillate outputs were studied. It was revealed that the daily productivity and the efficiency of the still were reduced as the mass of mass of sand was increased due to increased heat capacity of the sand. The use of 10 kg of sand resulted in daily productivity and efficiency of 4.005 kg/m^2/day and 37.8% respectively as compared to productivity of 2.852 kg/m^2/day with efficiency of 27% for the conventional solar still. The energy storage material improved yearly distillate output of the still by 23.8%.

Murugavel et al. [26] studied the performance of double sloped basin type solar still with various energy storing materials. The angle of inclination of the still was 30^0. The sides and bottom of the still were insulated with glass wool to reduce the heat losses. The different energy storage materials such as ¼ inch quartzite rocks, ¼ inch washed stones, mild steel scrap etc. were used in the basin of the still at depth of 0.5 cm. The experimental results indicated that the maximum distillate output was achieved with ¼ inch quartzite among all energy storage materials. For further improvement in the still production pieces of red brick and concrete were used at 0.75 mm water depth in the basin. The highest daily productivity was achieved with ¾ inch quartzite rocks. The temperature difference between basin water and glass cover was maximum when basin water temperature of the still was 60^{0}C. The study concluded that the distillate output was function of glass, water and atmospheric temperatures, temperature difference of water-glass and atmospheric-glass temperature difference. The experimental values of distillate outputs were close to theoretical values of productivity calculated from thermal model.

Tabrizi et al. [27] examined the behavior of weir type cascade still with latent heat storage material. The stepped absorber plate having 15 steps was used in the still and lengths of horizontal and vertical surface of the still were 3 and 5 cm respectively. The glass cover of the still was inclined at an angle of 30^0. Paraffin wax was the latent heat material used in the still. The thickness of layer of paraffin wax kept below the absorber plate was 3 cm. The heat losses from sides and bottom of the still were prevented by providing insulation of sufficient thickness. It was concluded that the residence time was increased due to weir on each step. The results indicated that the distillate output was maximum when flow rate of water was minimum. It was also possible to maintain the thin layer of water with the help of weir. The experimental results revealed that the distillate output of the still without latent heat storage material was higher than that of the still having latent heat storage material on sunny day. But on partially cloudy day, the distillate output of the still with the energy storage material was found to be 3.4 kg/m^2/day as compared to that of productivity of still without energy storage which was 2.1 kg/m^2/day. Therefore, the still with latent heat storage material was preferred for partially cloudy areas.

Murugavel et al. [28] fabricated a single basin double sloped still having various wick materials such as coir mate, sponge sheet, cotton cloth and waste pieces of cotton at mass of water in the basin, having an area of 1.74 m^2. The glass cover was inclined at an angle of 30^0. V-shaped drainage system was provided at lower edge of glass on both sides to collect condensate. Holes were drilled on the sides of the still, through which thermocouples were inserted and attached at different locations to measure temperature of various components. Insulating material was used to close holes to avoid vapor and heat losses. Experiments were carried out at an equivalent depth of 5 mm of water in the basin. Solar radiations were measured with the help of photovoltaic sun meter having tracking mechanism. Rectangular fins covered with cloth were also used in the still in different arrays to improve its performance. Among different wick materials, black cotton cloth was found to be more effective in improving the distillate output of the still. From different fin arrangements, the rectangular aluminium fins configured in length wise direction resulted in slightly higher productivity of the still than black cotton cloth. The experimental and theoretical values obtained from proposed model were compared with Dunkle model. It was observed that the variations of various actual and theoretical parameters were similar but deviations between these parameters were significant.

Srivastva et al. [29] investigated the performance of single slope single basin solar still having porous fins extended in the basin in order to receive radiations with minimum shading. The material used for construction of fins was black cotton rags. The basin area and angle of inclination of the still were 0.5 m^2 and 24^0 respectively. The evaporation rate was increased due to higher operating temperatures and early response of the still which resulted in increased distillate output of the still. The day time and overall daily productivities of the still were increased by 56% and 46% respectively. The experimental results indicated that the productivity of the still increased as depth of water in the basin decreased. The highest productivity of 7.5 kg/m^2 was obtained in month of may.

Srivastava et al. [30] theoretically and experimentally studied the performance of single slope basin type still in which multiple porous absorbers having low thermal capacity were floating adjacent to each other with the help of thermocol insulation. The basin area and slope of the glass cover of the still were 0.52 m^2 and 24^0 respectively. The performance of the modified still was compared with the conventional basin type still of exactly same dimensions. It was observed that the absorber temperature was higher than the basin water temperature. The results indicated that the still having porous absorbers performed better than the conventional basin type still because of higher absorber temperatures and early response of the still. The temperature difference between glass cover and porous absorber was large in comparison to the basin water and glass temperature difference of conventional still which resulted in higher distillate outputs. As basin temperature in the modified still was lesser, it resulted in reduced base and side losses. The average gain of yield on clear day was 68% whereas it was 35% on cloudy days. The experimental results demonstrated that there is some amount of drop in cumulative productivity of the modified still as depth of basin water changed from 1 to 2 cm, but beyond 2 cm depth there was not any significant change in productivity with further increment of basin water depth.

Kumar et al. [31] conducted experiments on concentrator integrated single slope basin type solar still having phase changing material. The glass cover of the still was placed at an angle of 11^0. Conical type of concentrator integrated with hemispherical basin was used in the experimental analysis. Paraffin wax was selected as phase changing material and placed in the basin by enclosing in the six copper balls. Each copper ball was painted black to allow absorption of solar radiations. A small hole on the top of copper ball allowed filling of wax and was sealed with the help of rubber cork. Hourly variations of different temperatures such as glass cover outer-inner, basin water, ambient were measured by using thermocouples of K-type. The maximum temperatures of water achieved in the basin of the still with and without phase changing material were 93^0C and 89^0C respectively. It was observed that PCM worked as heat source for basin water during night. The experimental results showed that the use of phase changing material was more effective at lower depths of basin water after sunset. The maximum productivity of solar still augmented with concentrator and having PCM was 4460 ml/m^2/day. Integration of concentrator with still having paraffin wax improved the productivity of the still by 26%.

Ansari et al. [32] carried out numerical calculations to assess the performance of single slope basin type solar still having heat storage material under the basin liner. The basin area of the still was 1 m^2. Experiments were performed by using three different kinds of phase changing materials. The thickness of layer of PCM and depth of water maintained in the basin were 0.08 m and 0.07 m respectively. Hourly variations of different components like basin water temperature, phase changing material temperature, heat transfer coefficients, energy absorbed per second during charging and discharging of PCM were plotted. The experimental results demonstrated that the basin water temperature of the still increased up to 3:00 PM and decreased thereafter. The results indicated that the rate drop in basin temperature was lower when melting temperature of the phase changing material was higher. The charging and discharging of PCM was significantly dependent on melting temperature of the PCM. It was revealed that the excess energy stored in the phase changing material worked as heat source at night or even during cloudy days. It was also reported that the selection of PCM was also influenced by the maximum basin water temperature that can be attained.

Sebaii et al. [33] investigated the performance of single slope basin type solar still augmented with fins in order to increase rate of heat transfer from liner to water kept in the basin of the still. The effects of various fin configuration parameters namely number of fins, height and thickness of fins on efficiency and distillate output of the still were studied. The effect of shadow area of fins on the yield of the still was also analyzed by changing the number of fins. The results proved that the performance of basin type solar still can be improved by integrating fins in the basin of the still. It was observed that the distillate output of the still having fins in the basin was increased by increasing height of fins; however, it was reduced by increasing the thickness and number of fins in the basin of the still. The hourly productivity of the still having fins in the basin was decreased when mass of water in the basin was increased during day time but distillate output was increased during night because of increased heat capacity of water in the basin of the still. The experimental results demonstrated that the daily distillate output of 5.377 kg/m^2/day was achieved when 7 fins, each of height 0.04 m and thickness 0.001 m was used in the basin.

Hansen et al. [34] analyzed the performance of inclined solar still having wire mesh and various wick materials. The basin area and the angle of inclination of glass cover were 0.75 m^2 and 30^0 respectively. Stepped absorber was painted black to retain the water in the basin of the solar still. Different wick materials were characterized on the basis of properties such as water repellence, capillary rise, porosity, absorption and heat transfer coefficient. Hourly variations of temperatures of different still components, cumulative productivity of the still and production rate were plotted. The water was fed with the help of distribution pipe having 20 holes drilled at an equal interval on it. Temperatures of different elements of still such as glass cover, absorber plate, inlet water, condensed water and wick surface were measured by using K-type thermocouples having digital display. It was found that water coral fleece was most suitable material for higher productivity of the still. Increase in productivity was observed by provision of wire mesh on wick. The performances of stills having various wick materials on different absorber plate configurations were compared. Maximum yield of 4.28 l/day was achieved in the still having combination of water coral fleece and stepped absorber with wire mesh in the basin of the solar still.

Matrawy et al. [35] modified the conventional basin type still with the use of corrugated wick and inclined reflector. Corrugated wick was made by using 2 mm thick black cloth and was partially immersed in water. Transparent glass of thickness 6 mm was selected as cover material of the still. Inclined reflectors were used to increase the amount of solar radiations falling on the plane of solar still. The numerical calculations were carried out by formulating and solving energy balance equations. The performance of modified still was compared with the conventional basin type still of same dimensions under similar ambient conditions. Temperatures of different elements of the still were recorded with the help of K-type thermocouples. It was observed that the maximum temperature of 87^{0}C was achieved incorrugated wick. The results demonstrated that the glass cover temperature of simple basin type still was lower than that of the still having corrugated wick because of higher temperature of wick surface. An increment of 34% in the productivity was obtained for the modified still as compared to the conventional still. It was also concluded that the best angle of inclination of reflector with respect to vertical direction was 30^0.

Elango et al. [36] performed various experiments on basin type still with various water nanofluids. Water nanofluids of aluminium oxide, zinc oxide, iron oxide and tin oxide were tested at different concentrations in the solar still. The basin area and slope of glass cover of the still were 0.25 m^2 and 30^0 respectively. The heat losses from the basin of the still were minimized by providing thermocol insulation of 0.038 m thickness. The thermal conductivity and stability evaluation of all nanofluids was carried out in this study. It was observed that all nanofluids were stable at 0.1 % concentration. The results indicated that the thermal conductivity of aluminium oxide nanofluids was highest. It was concluded that the basin fluid temperature and distillate outputs were strongly influenced by thermal conductivity of nanofluids. Higher temperature of basin fluid was obtained for aluminium oxide having highest thermal conductivity among all nanofluids and hence distillate output was also highest for the same. The use of aluminium oxide nanofluids in the basin of conventional still resulted in 29.95% improvement in productivity of the still. It was also estimated that the cost of system was increased by 22.5% because of extra cost imposed by nanofluids.

Ibrahim et al. [37] investigated the performance of basin type solar still augmented with air cooled condenser and vacuum pump. The basin of the still was constructed of carbon steel of 0.003 m thickness and area of the basin was 0.25 m^2. The glass cover of the still was given curvature, so that it can able to withstand pressure difference. The condenser was consisted of copper tube of bore 0.1 m and fins were applied on the circumference of tube to enhance the dissipation of heat. Pressure difference of 15 kPa was maintained between basin and condenser by running vacuum pump for five minutes before daylight to enhance movement of vapors from evaporation chamber to condenser side, where they can be condensed and also evaporation rate was increased because of reduced pressure. It was observed that the condenser temperature was higher than atmospheric temperature due to which latent heat of condensation can be easily dissipated from condenser to atmosphere. The productivity of modified still was 16.2% higher than that of the conventional still with increase in efficiency of 30%. The cost of distillate output from modified still was 17% higher than that of the conventional still.

Alaian et al. [38] experimentally investigated the performance of solar still having pin finned wick in the basin. The material used for construction of still was galvanized steel of 1 mm thickness. Any loss of vapors from still to atmosphere was prevented by applying rubber and silicon between frame and glass cover of the still. The slope of the glass cover and basin area of the still were 17^0 and 1 m^2 respectively. The sides and bottom of the basin of the still were insulated with the help of glass wool of thickness 5 cm to minimize the heat losses from the still. The use of pin finned wick resulted in the enhancement of surface available for evaporation. The material that was chosen for wick was jute cloth. The experimental results indicated that the maximum basin water temperature achieved was 71^0C whereas the maximum temperature attained by wick surface was 67.8^0C. It was found that the increment in distillate was strongly influenced by ambient conditions. The cumulative distillate outputs were increased when pin finned wicks were placed in the basin of the still. Improvement of 23% in productivity was obtained by augmenting pin finned wick in the conventional basin type solar still. The values of maximum distillate outputs obtained for the still integrated with finned wicks and the conventional still were 4.87 l/m^2 and 4.19 l/m^2 respectively.

Omara et al. [39] assessed the performance of single slope solar still with wick and reflectors. The glass cover of thickness 3 mm was inclined at an angle of 30^0 with horizontal. The heat losses from sides and bottom were prevented by using 30 mm thick layer of fiberglass. The absorber plated which was consisted of corrugated wick in the wave form having 80^0 angles between any two consecutive peaks or valleys and height 50 mm. The performance of modified still was compared at three different depths of water in the basin. It was observed that the glass cover and basin water temperatures of the still having corrugated wick were higher than that of the conventional basin type solar still because of enhanced surface area in case of modified still. The drawback of wick type of still was that it did not produce any distillate during clouds. The use of corrugated plate as base enhanced the productivity of still by 55.36% over the conventional still. It was revealed that addition of wick to corrugated base increased the distillate output by 90% and daily efficiency was found to be 49.3%. The yield of corrugated still with wick and reflectors was more than the conventional still by 145.5% with daily efficiency of 59%. The daily efficiency of conventional still was 33%.

Samuel et al. [40] did experiments to improve distillate output of conventional solar still by using energy storage medium in the basin. The performance of the modified still was also compared with the simple basin type solar still having sponge in the basin. The basin area and the angle of inclination of glass cover were 1 m^2 and 13^0 respectively. The energy storage materials used in the still were spherical balls containing salt and sponge. The results indicated that the basin surface temperature was more than water temperature during morning hours but during off sunshine hours basin water temperature was higher because of heat liberated from spherical balls which was stored during sunshine hours. It was observed that the maximum basin water temperature of 87^0C was achieved in the solar still having spherical balls placed in the basin because of heat transfer from stored heat in upper portion of ball to lower one. The daily distillate output was highest with spherical ball having salt and found to be 3.7 kg/m^2, whereas for the still with and without sponge, it was 2.4 and 2.6 kg/m^2 respectively. It was concluded that the sponge should be changed after two weeks as rust and salt got accumulated in the pores. From economical point of view, still with spherical balls gave low cost of water and payback period was 4.3 months.

Kabeel et al. [41] modified the conventional basin type still by placing latent heat storage material in the basin. Paraffin wax was used as phase changing material in this study. The area of the basin of the still was 0.615 m^2. The glass cover of thickness 3 mm was inclined at an angle of 30.47^0. The base and sides of the solar still were insulated by using fiberglass of 5 cm thickness to minimize the heat losses from the basin of the still. Silicon was used as sealant to prevent any loss of vapors from basin of the still to atmosphere. Phase changing material worked as heat source during low solar intensity period to maintain temperature difference with the outer glass. It was observed that the maximum basin water temperature achieved in the still having PCM was 82^0C which was higher than that of the conventional still because PCM acted as heat source during periods of low solar intensity. The results of the experiment proved that the daily distillate output for the still with PCM was higher than that of the conventional still. The productivity of the still with PCM was 7.54 l/m^2/day while its value was 4.51 l/m^2/day for the conventional still. The output of the still with PCM was 67-68% more than that of the conventional one. Assuming life span of solar still to be 10 years, the cost of one liter of distillate from still with PCM was found to be 0.03 $, whereas it was 0.032 $ for conventional basin type solar still.

Feilizadeh et al. [42] experimentally studied the performance of single basin single slope solar still having 0.56 m^2 basin area and cover slope of 30^0. The experiments were carried out using four stills in different seasons to study the effect of water depth while maintaining constant water cover distance. The temperatures at different locations of the still were measured with the help of K-type thermocouple. All the values of temperatures and distillate outputs were recorded after an equal interval of one hour. It was proved that by varying water surface cover distance from 9 to 23 cm; the productivity of still can be increased by 26%. Thus, it was revealed that in the investigation of stills for different water depths, constant water surface cover distance should be maintained. It was observed that the increased water depths lead to reduced and enhanced basin water temperatures during day and night respectively. The results showed that with increasing water depth, the nocturnal productivity of the still was also enhanced. By comparing results of empirical relation developed between yield and water depth, it was concluded that the past researchers presented a lower dependency of distillate output on water depth because in their study water surface cover distance was varied along with water depth.

Chapter 3

Experimental Setup and Procedure

3.1 Experimental Setup

A schematic diagram of single basin single slope solar still having float wick in the basin is shown in Figure 3.1. The frame of the solar still was made up of mild steel because of its high tensile strength. The material of construction of the basin of the solar still was stainless steel as it has high resilience and ductility. The evaporating surface area of the basin was 1.5 m × 0.77 m. The top of the basin was covered with transparent glass inclined at an angle of 30°, which is nearly equal to latitude of Patiala, India (30.35°N, 76.37°E). The back plate and both triangular sidewalls of the basin were consisted of reflecting surfaces as shown in Figure 3.2, so that radiations can be reflected into the basin.

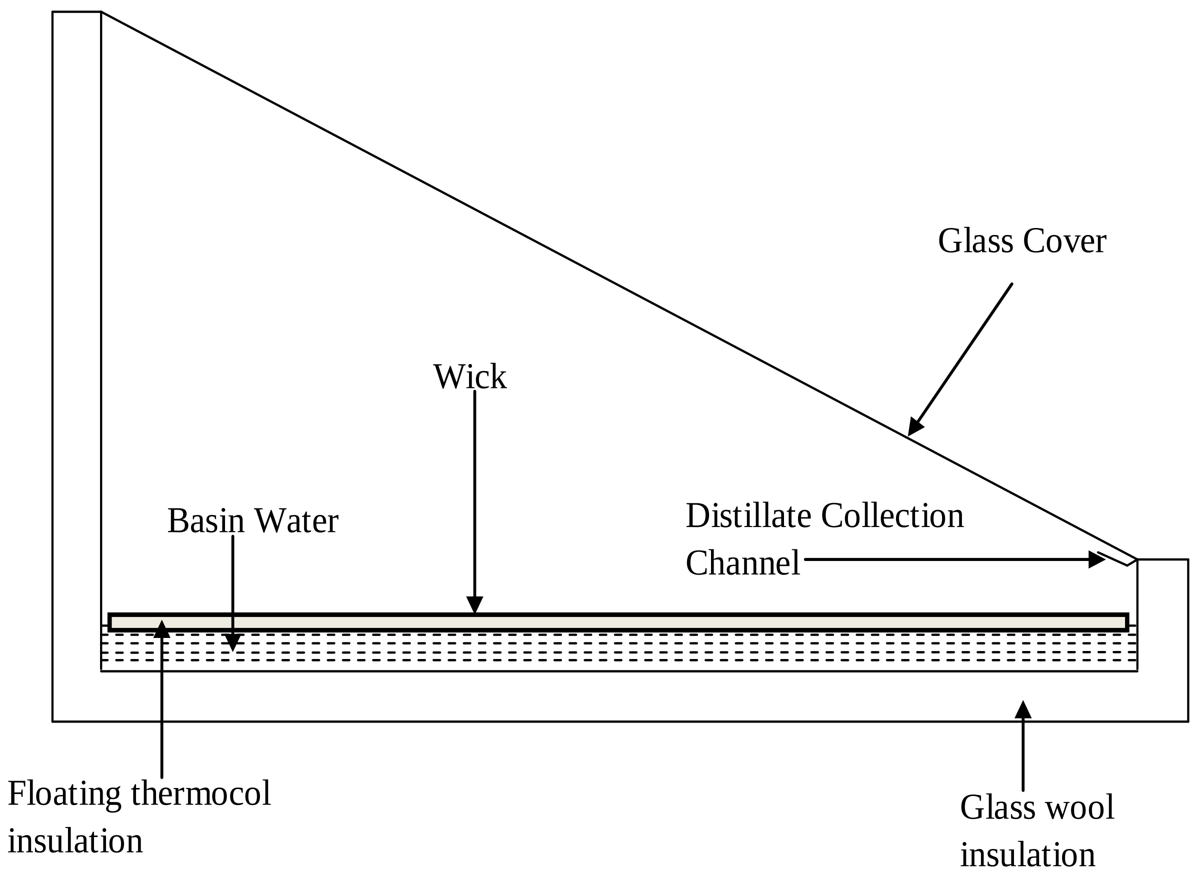

Figure 3.1. Schematic diagram of modified still

Figure 3.2. Reflectors on sidewalls and back plate

Multiple floating wicks were placed adjacent to each other in the basin as shown in Figure 3.3 to reduce the thermal inertia of the evaporating surface. A float should be able to withstand elevated temperatures in the basin of the still and must be strong, light weight, water resistant with time. Thermocol is the best material which fulfill all these requirements below 80^0 C which is the maximum temperature achieved in the basin of the still. The float was made from thermocol sheet of thickness 19 mm on which protective layer of 4 mm thick sheet of polyurethane foam was provided to prevent any burnout due to high temperatures. A black cotton cloth of 1 mm thickness was wrapped on this float and fastened with the help of cotton threads. The length and width of the wick were 740 mm and 62.5 mm respectively. Sufficient clearance was provided between the float and sidewalls of the basin so that the float does not get stuck up as water level in the basin changes.

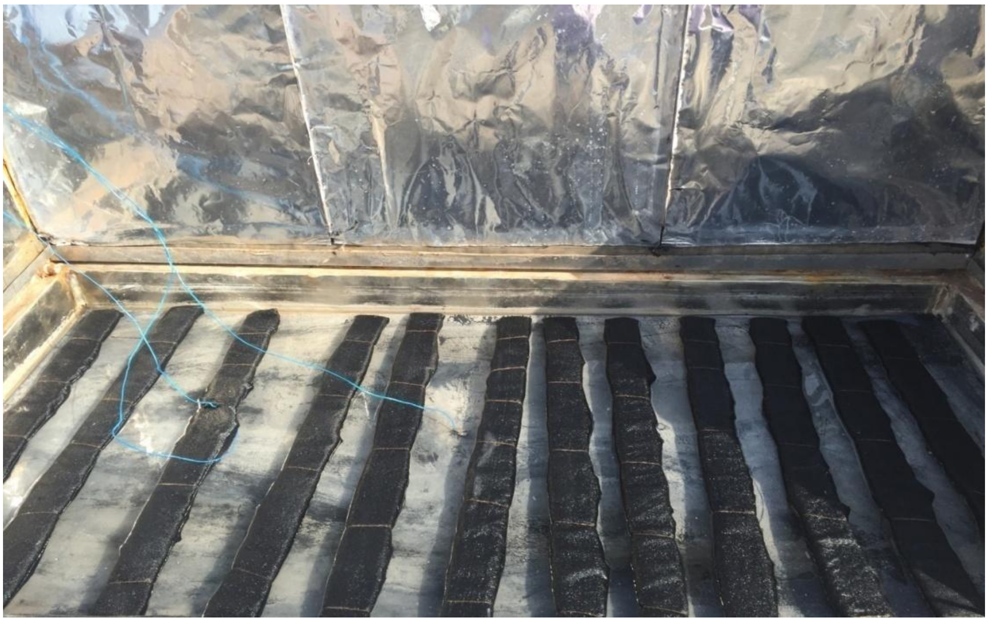

Figure 3.3. Float wick in the basin of the still

Insulation was provided on the sides and bottom of the basin as shown in Figure 3.4 in the still with the help of casing of galvanized iron sheet to prevent the heat losses. The material selected for insulation was glass wool. The condensed distillate was collected in the channel consisted of polycarbonate sheet. Sufficient slope was given to channel for smooth flow of distillate which was further accumulated in the plastic container.

Figure 3.4. Insulation on the back plate of the still

Black rubber of 10 mm thickness was kept in the basin to absorb maximum of the incident solar radiations. Leakage of vapors to atmosphere from the basin of the still was prevented by placing rubber gasket between glass cover and frame. The edges of the basin were made leak proof with the help of silica gel sealant. The performance of modified still was compared with another conventional basin type still of exactly same dimensions and material, which is referred as reference still in this study. The pictorial view of both modified and reference stills is shown in Figure 3.5.

Figure 3.5: Pictorial view of modified and reference still

The specifications of various components of the solar still are given in the Table 3.1.

Table 3.1. Technical specifications of different components of the solar still

S no.	Still Component	Specification
1	Evaporating surface area of basin	1500 mm × 770 mm
2	Effective glass cover area	1470 mm × 900 mm
3	Angle of inclination of glass cover	30°
4	Thickness of glass cover	5 mm
5	Insulation thickness	75mm
6	Basin liner	Black butyl rubber

3.2 Experimental Procedure

The test procedure was started by checking both the stills viz. the reference still and the modified still for their synchronization. For this, same amount of water was filled in the basin of both the stills and their hourly distillate outputs were measured simultaneously for two days. The similar values of the productivities of both the stills showed that their performance was well in synchronization with each other.

Figure 3.6. Pyranometer (Make: Kipp and Zonen)

After calibration, the different sets of experiments were conducted in the outdoor environment during the month of May. Each experiment was carried out for one day (24 hours). The total solar radiation intensity was measured by using pyranometer (Make: Kipp and Zonen & Model: CMP11) shown in Figure 3.6. The operational temperature range of this instrument is -40°C to 80°C. The response time of the pyranometer is less than 5 seconds with maximum irradiance of 4000 W/m^2. The field of view of this model of pyranometer is 180°.

Ambient air temperature and temperatures at various locations of both the stills were measured with the help of T-type thermocouples. This type of thermocouple offers wide range of operating temperature of -270°C to 370°C. The accuracy of T-type thermocouple lies within the limits of ±1°C. These temperatures were continuously logged by 64 channel data logger shown in Figure 3.7. Wind velocity was measured with the help of hot wire anemometer. The readings from all instruments were logged after an interval of 10 minutes.

Figure 3.7. 64 Channel Data Logger

Distillate outputs from both the stills were collected hourly in the plastic containers, between 9:00 AM to 5:00 PM and weighed on digital weighing balance shown in Figure 3.8 having least count of 0.1 gram. The nocturnal distillates, collected from 5:00 PM to 9:00 AM were measured next day in the morning.

Figure 3.8. Digital weighing machine

The effect of covering evaporating surface area with float wick in different proportions at the basin water depth of 5 cm has been studied. The performances of both the stills were also compared at four different depths to investigate the effect of basin water depth. The present work has been carried out by considering four different cases as given below:

a) Case 1: 100% basin water surface was covered with float wicks.
b) Case 2: 75% basin water surface was covered with float wicks.
c) Case 3: 50% basin water surface was covered with float wicks.
d) Case 4: 25% basin water surface was covered with float wicks.

Chapter 4

Results and Discussion

As mentioned earlier, the experiments were performed by considering four different cases of modified still. In case 1, case 2, case 3 and case 4, the portions of the basin area covered with float wick were 100%, 75%, 50% and 25% respectively.

4.1 Test Results of Case-1:

The experiment with 100% basin area covered with float wicks was performed on 27thApril, 2017. The solar intensity and ambient air temperature variations on this date are shown in Figure 4.1. It can be seen from graph that solar intensity and ambient air temperature were maximum around 12:30PM and 3:30PM respectively.

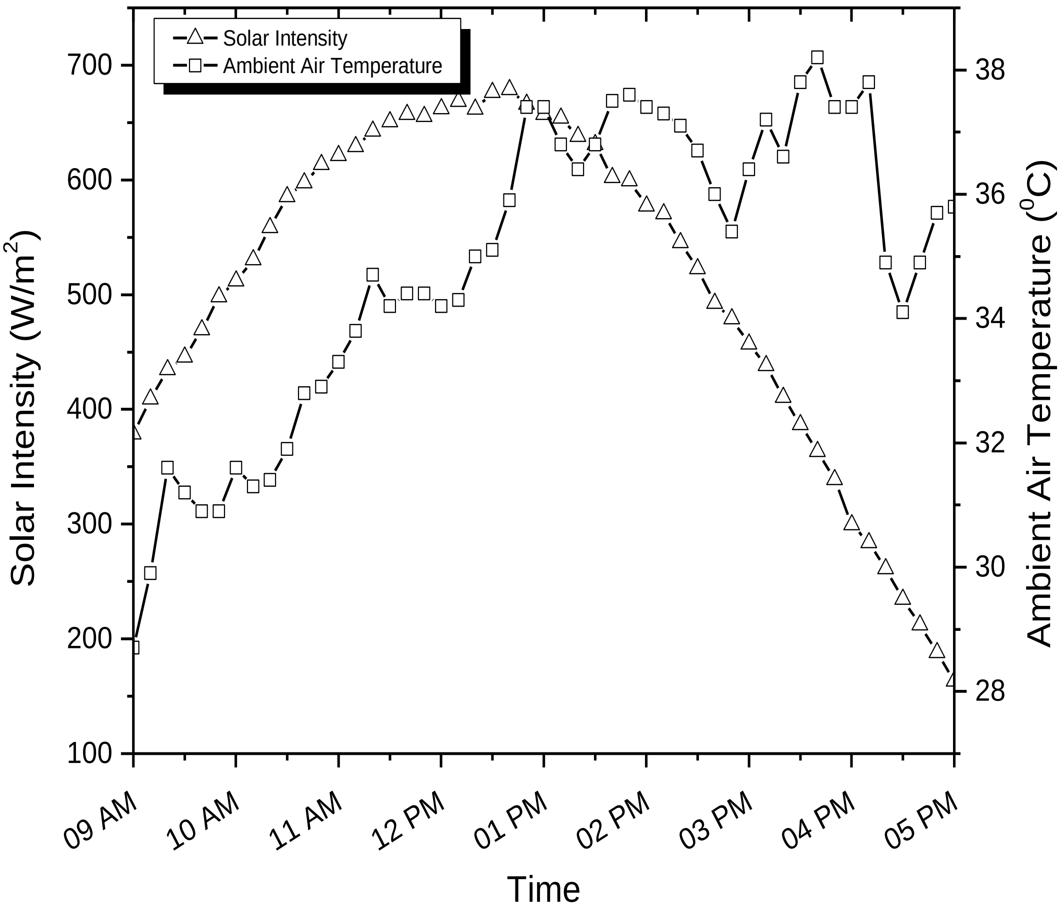

Figure 4.1. Variation of solar intensity and ambient air temperature on 27thApril, 2017

Figure 4.2 shows the variation of cumulative productivity from 9:00AM to 5:00PM for the tested stills when complete evaporating surface area was covered with float wick. It is found that the cumulative distillate output for the still having float wick in the basin is higher than that of the reference still. The reason for this increase in productivity was use of float wick in the basin, which reduced the thermal inertia of the basin water leading to early response of the still. The cumulative distillate output for the modified still during day time was 2.29 kg/m^2, and 1.8 kg/m^2 for the reference still. The productivity gain of 27.16% was obtained for modified still over the reference still when complete basin area of the modified still was covered with float wicks.

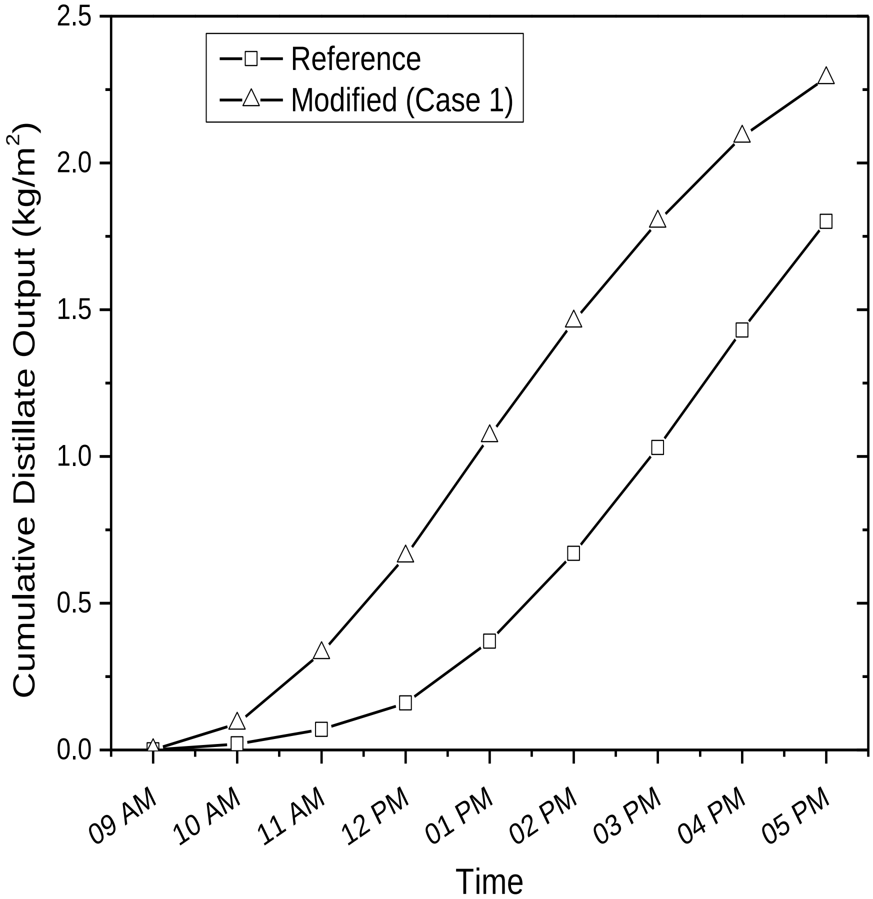

Figure 4.2. Variation of cumulative distillate output of reference and modified still (case 1) during day time (9:00AM to 5:00PM)

4.2 Test Results of Case-2:

The experiment with 75% basin area covered with float wicks was performed on 8th May, 2017. The variation of solar intensity and ambient air temperature during day time (9:00AM to 5:00PM) is shown in Figure 4.3. It can be observed that there is time lag between points of maximum ambient air temperature and solar intensity.

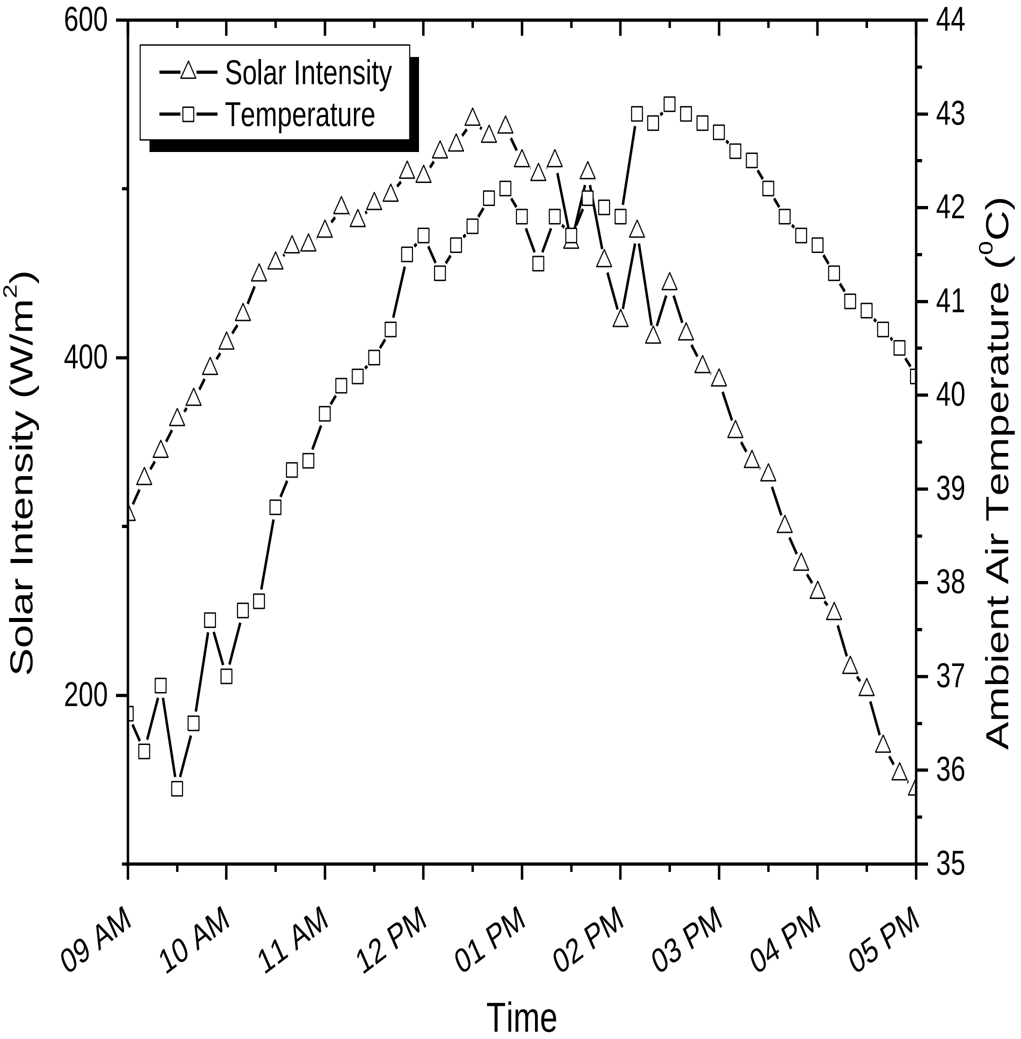

Figure 4.3. Variation of solar intensity and ambient air temperature on 8thMay, 2017

The variation of cumulative distillate output of reference and modified still for day time when 75% of the evaporating surface area is covered with wick is shown in Figure 4.4. The performance variation of the modified still was similar to the case when complete basin was covered with wick but increase in productivity was higher in the case 2. The cumulative distillate productivities for the both modified and reference stills during 9:00AM to 5:00PM in this case were 1.85 kg/m^2 and 1.25 kg/m^2 respectively. It was found that the day time distillate output of the modified still was 48.1% higher than that of the reference still in case 2.

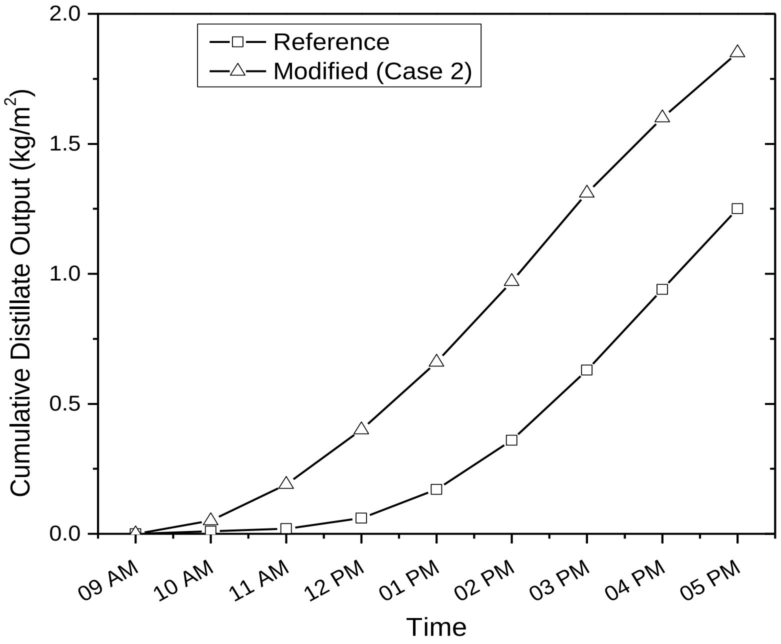

Figure 4.4. Variation of cumulative distillate output of reference and modified still (case 2) during day time (9:00AM to 5:00PM)

4.3 Test Results of Case-3:

The experiment with 50% basin area covered with float wicks was performed on 9thMay, 2017. The solar intensity and ambient air temperature variations are shown in Figure 4.5.

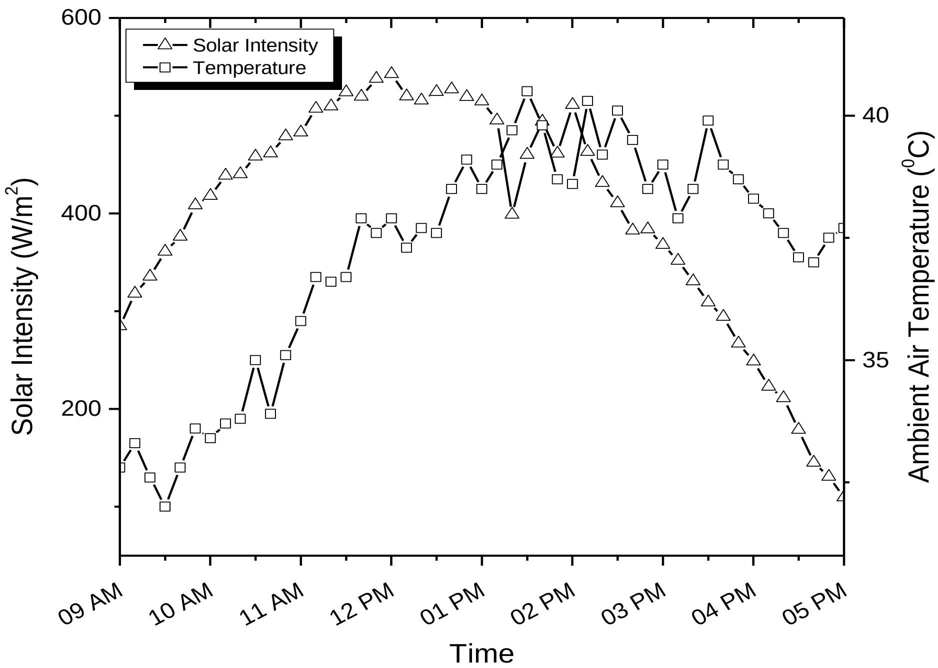

Figure 4.5. Variation of solar intensity and ambient air temperature on 9thMay, 2017

Figure 4.6 shows comparison of cumulative productivity of both modified and reference stills when float wick was placed in 50 percent of the total available basin area. The results demonstrated that the yield of modified still during was higher than that of the conventional still but rise in productivity was less than that of the case 2. This was due to increased heat capacity of basin water as half of the basin surface area was exposed to direct solar radiations. For modified and reference stills, the cumulative distillate output during day time was 1.76 kg/m^2 and 1.38 kg/m^2 respectively. . The productivity gain of 27.57% was obtained for modified still over the reference still in case 3.

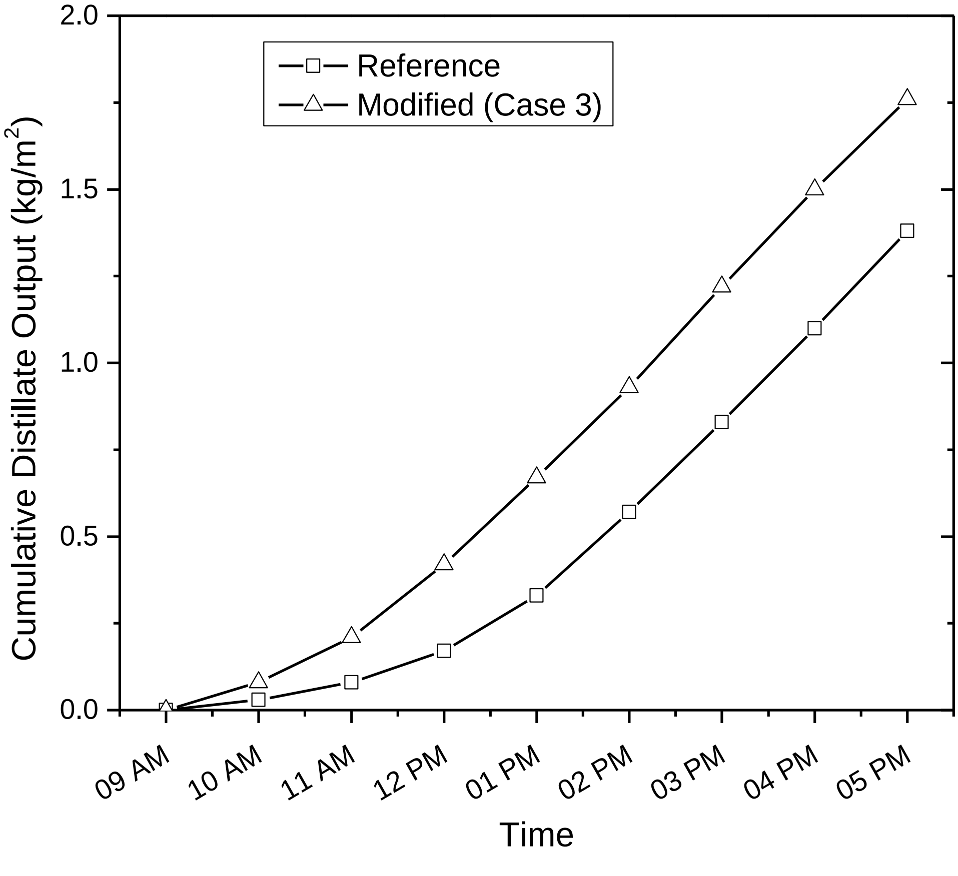

Figure 4.6. Variation of cumulative distillate output of reference and modified still (case 3) during day time (9:00AM to 5:00 PM)

4.4 Test Results of Case-4:

The experiment with 25% basin area covered with float wicks was performed on 10thMay, 2017. The variation of solar intensity and ambient air temperature during day time (9:00AM to 5:00PM) is shown in Figure 4.7.

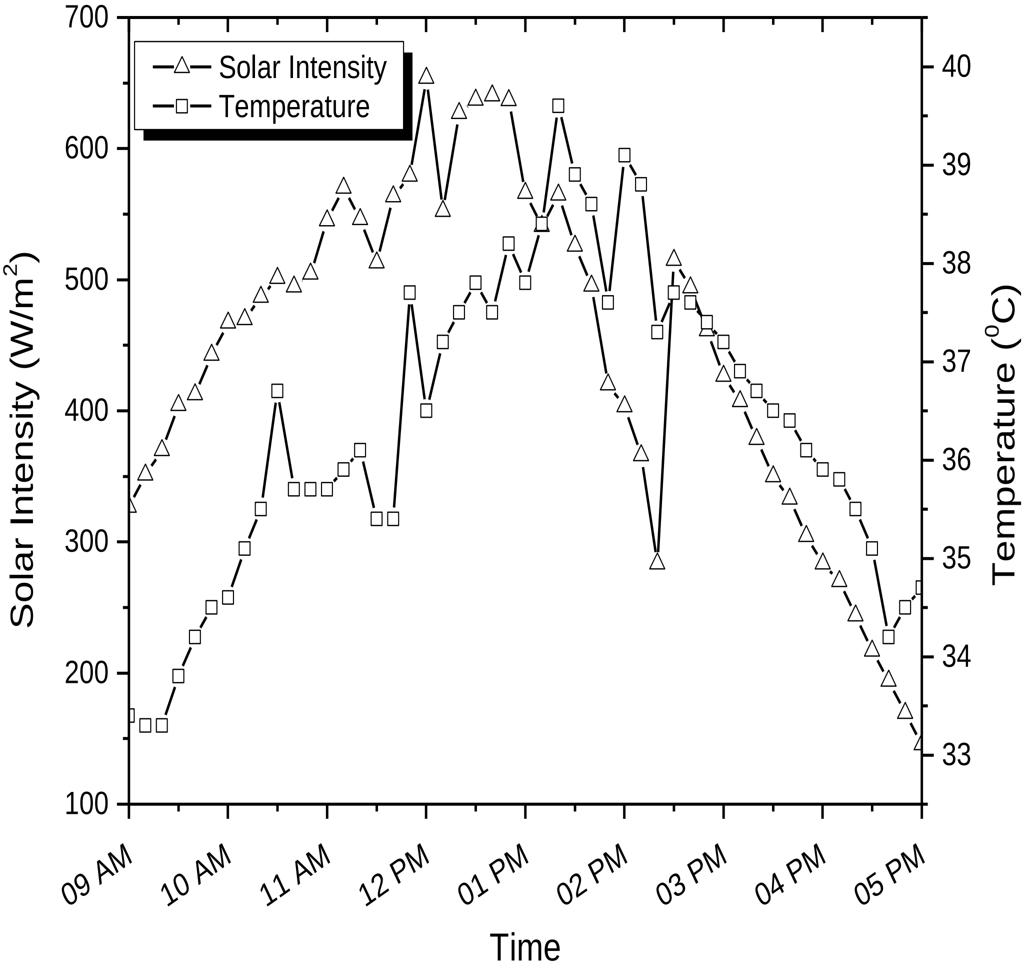

Figure 4.7. Variation of solar intensity and ambient air temperature on 10thMay, 2017

The deviation of cumulative productivity of modified still from reference still during sunshine hours when 25 percent of the evaporating surface area is covered with wick is shown in Figure 4.8. It can be seen that cumulative distillate output of modified still is always more than that of reference still but increment in productivity is lesser than that of case 3 because of further increase of heat capacity of basin water in case 4. The behavior of performance variation of modified still with respect to conventional still is similar in both the cases. The values of cumulative distillate output for both modified and reference stills were 1.57 kg/m^2 and 1.42 kg/m^2 respectively. . It was found that the day time distillate output of the modified still was 27.17% higher than that of the reference still when 25% of the basin water surface area was covered with float wicks. From Figure 4.2, 4.4, 4.6 and 4.8 it was observed that as percentage of basin covered with float wick decreased, the cumulative yield of the solar still first increased and thereafter decreased which indicated that the day time distillate output was maximum in case 2.

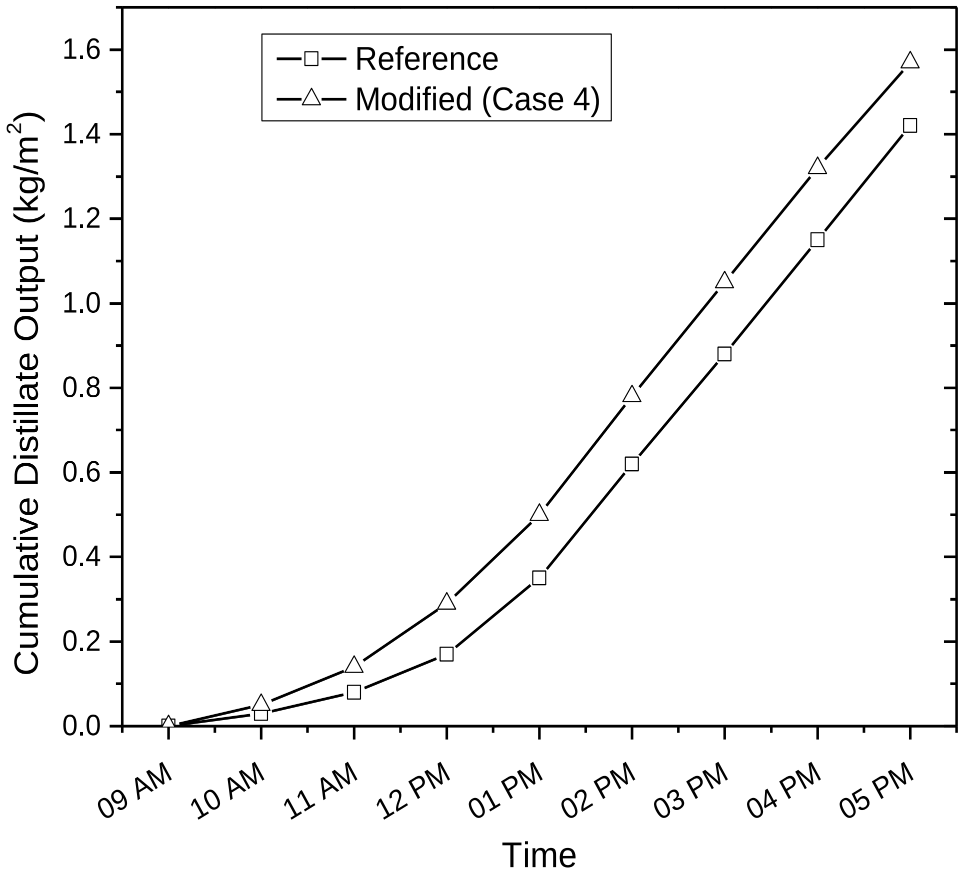

Figure 4.8. Variation of cumulative distillate output of reference and modified still (case 4) during day time (9:00AM to 5:00 PM)

4.5 Comparison of modified and reference still for all four cases

The productivity gain of modified still over reference still against percentage of evaporating surface area covered with float wick during day time is shown in Figure 4.9. The distillate output of modified still over reference still was increased by 10.52%, 27.57%, 48.11% and 27.17%, when percentages of basin area covered with wick were 25, 50, 75 and 100 respectively. The maximum gain of 48.11% in productivity was obtained when 75% surface area of basin water covered with wick. It was because of increased basin water temperature, which resulted in higher evaporation rate when 1/4th of the basin was exposed to direct solar radiations. The gain in productivity was reduced as surface area of the basin covered with wick decreased due to increased heat capacity of basin water. It can be seen that increment in distillate output is strongly influenced by percentage of the evaporating surface area of the basin which is under float wick.

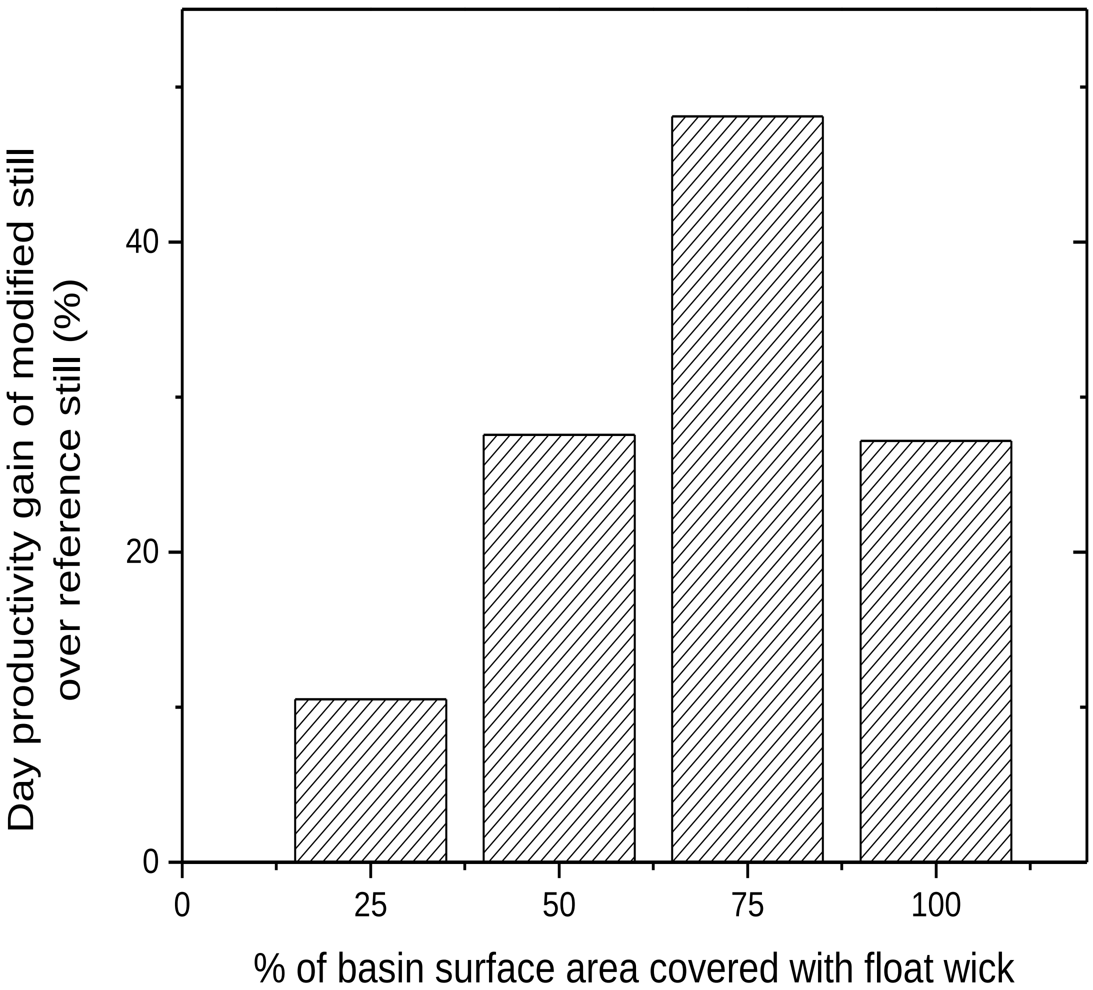

Figure 4.9. Comparison of day productivity gain of modified still over reference still (9:00AM to 5:00PM) for all the four cases of modified still

It was found from the experimental results of nocturnal distillate outputs modified and reference still that the nocturnal distillate output of all the four cases of modified still were lesser than the reference still. Figure 4.10 shows decrement in nocturnal (5:00PM to 9:00 AM) yield of the modified still over conventional still against the proportion of basin surface area covered with float wick. The maximum reduction of 20.08% in productivity was found, when evaporating surface area was completely covered by floating absorber. The reason for drop of nocturnal productivity in modified still could be hindrance provided by float wick in transfer of heat from basin water to upper surface of wick. Heat is carried away from basin water to upper surface of floating absorber by warm water due to capillary rise. But when basin is partially covered with wick, heat can directly flow from basin water to top surface of wick. The drop of 20.08%, 2.46%, 0.59% and 5.11% in productivity was obtained when percentages of the basin covered with floating absorber were 100, 75, 50 and 25 respectively.

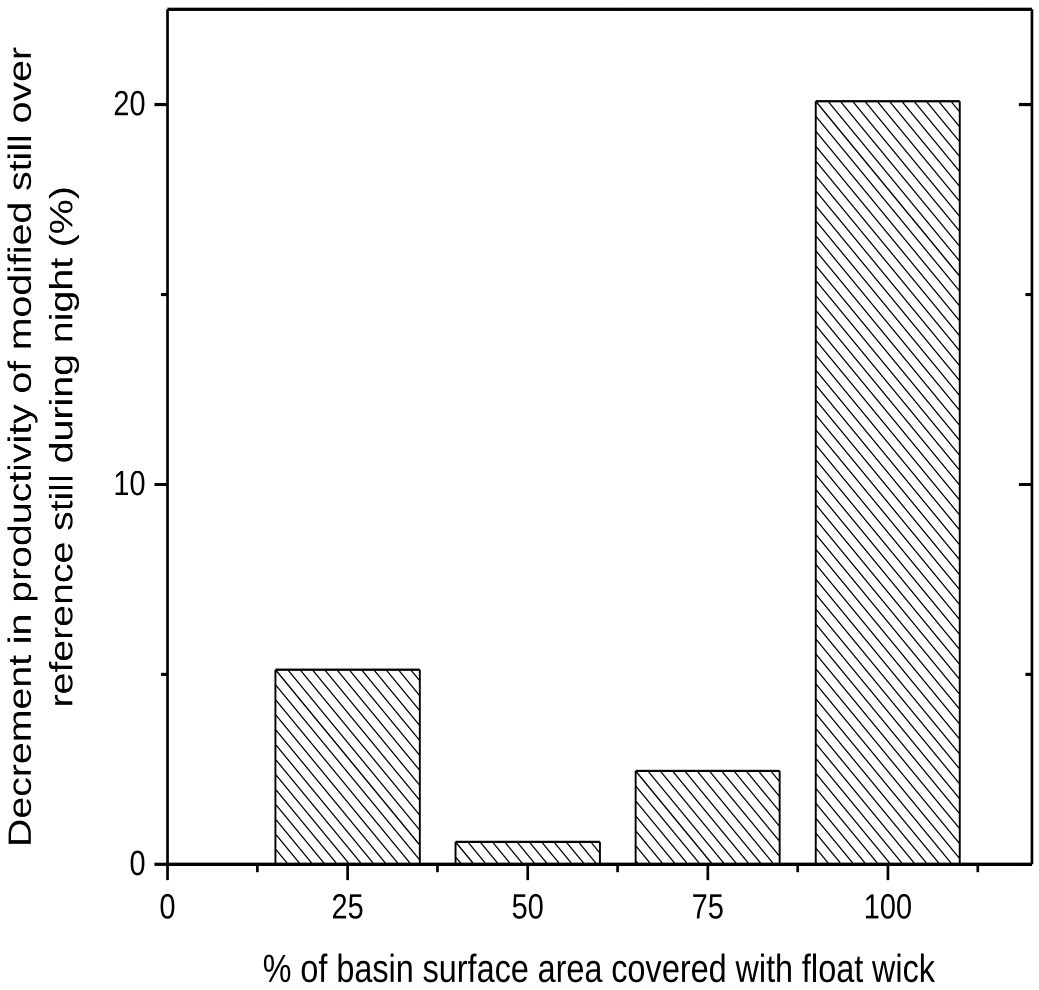

Figure 4.10. Comparison of total nocturnal (5:00PM to 9:00AM) distillate output of all the four cases of modified still

The gain in total distillate output for 24 hours against percentage of basin surface area under float wick is shown in Figure 4.11. The productivities of modified still were improved by 3.83%, 20.57%, 13.33% and 2.86% when percentages of basin area below the float wick were 100, 75, 50 and 25 respectively. The rise of 20.57% in productivity of modified still over conventional still was observed when 75 percent of the evaporating surface area was covered with wick. The gain of distillate output was highest and drop in yield of the solar still over the reference still was lowest for the case, when 3/4th of the basin surface area was kept under floating absorber.

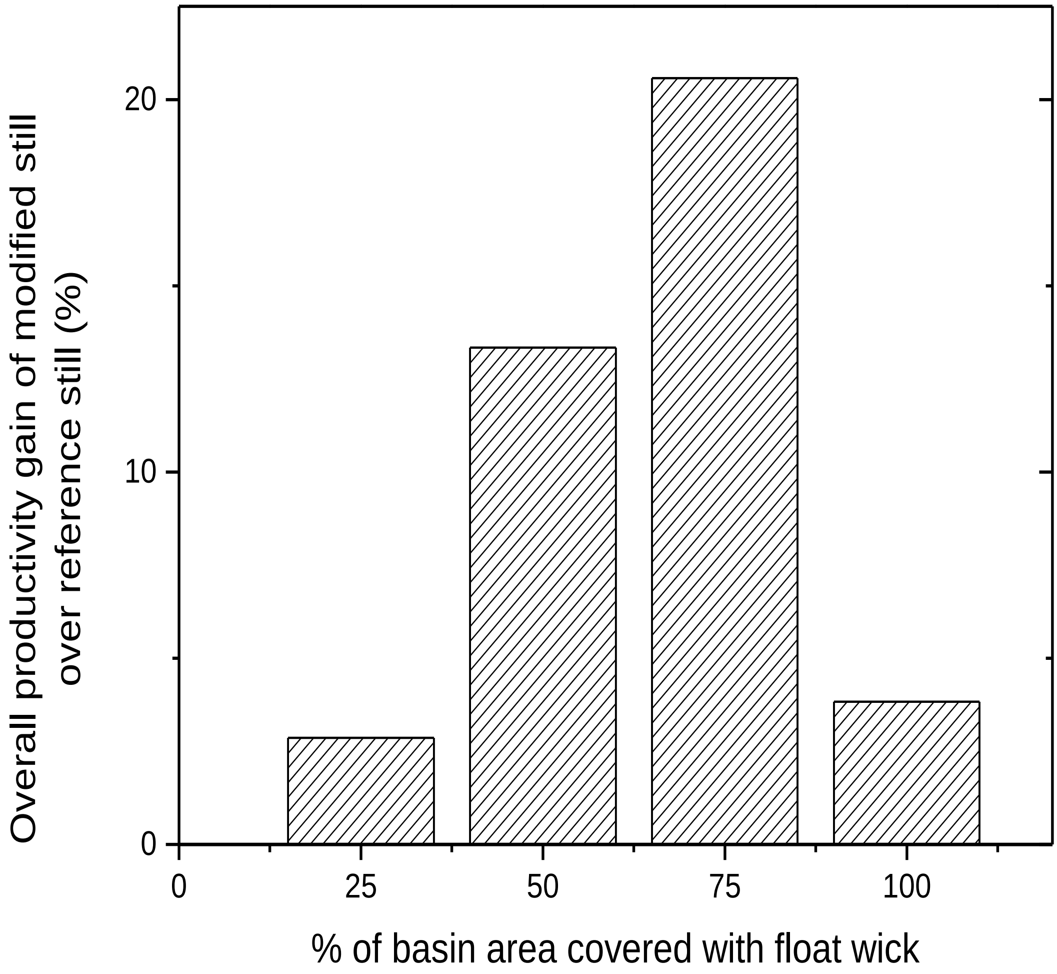

Figure 4.11. Comparison of overall distillate output for 24 hours (9:00AM to 9:00 AM) of all the four cases of modified still

It can be seen from Figure 4.11 that the overall daily productivity gain of modified still over reference still was maximum for case 2, i.e., when 75% of the basin surface area was covered with float wick. Hence, component wise performance for case 2 of modified still is presented in Figure 4.12 to Figure 4.15.

From Figure 4.12 , it can be seen that the basin temperatures of the reference still are higher than that of the modified still during day time which is the indication of higher heat losses through the sides and base of the reference still. Due to these reasons, the performance of the modified still was better than that of the reference still. It was also observed that the basin water temperatures of the modified still were higher than that of the reference still during night which showed that the heat stored in the modified still was not fully utilized, thus decreasing its nocturnal distillate output. The maximum values of basin water temperatures in the modified and reference still were 65.55°C and 67.8°C respectively.

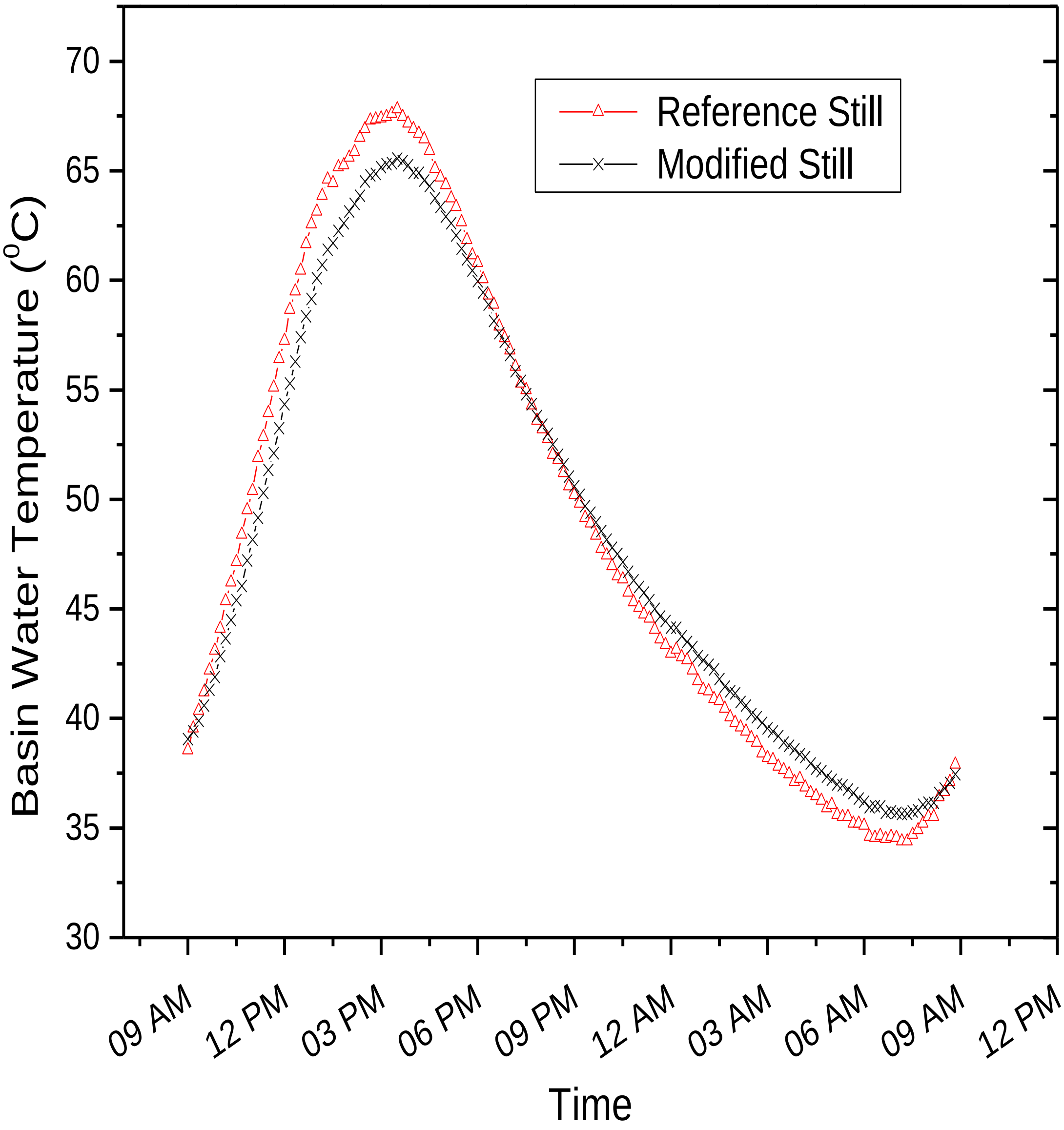

Figure 4.12. Basin water temperatures of modified and reference still for 24 hours (9:00AM to 9:00AM)

The hourly variation of temperatures of the various components of the modified still is shown in Figure 4.13. The temperature of the float wick is much higher than that of the basin water temperature of the modified still during sunshine hours which indicated that the still operated at much higher temperatures. Also, the lower basin water temperature of the modified still resulted in reduced base heat losses. It can be seen that temperature of float wick was lesser than that of the basin water temperature after 6 PM, which resulted in lower evaporation rate of water through the surface covered with float wick leading to decreased distillate output of the still during off sunshine hours.

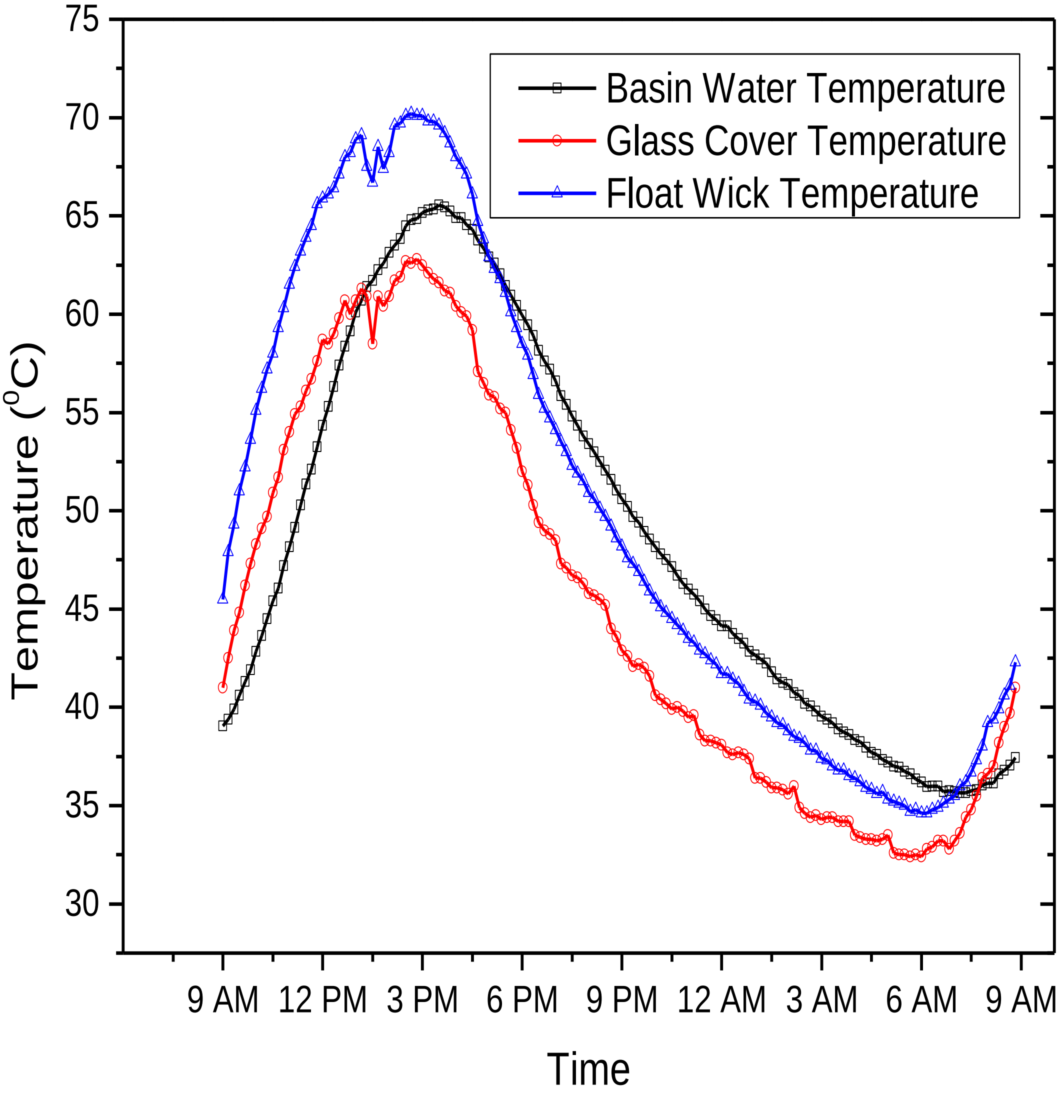

Figure 4.13. Component temperatures of the modified solar still

Figure 4.14 shows the variation of glass and surface temperatures of the modified and reference stills. It can be seen that, the maximum temperature of float wick is reached at about 15:00 h as compared to around 16:00 h for the basin water of the reference still. This earlier response is due to low thermal inertia of the float wick, which results in higher operating temperatures of the modified still leading to quicker start up in the morning as compared to slow response of reference still having large thermal capacity of basin water. There is significant difference between float wick temperature and glass cover temperature of modified still, whereas for reference still the basin water-glass cover temperature difference is lesser than the temperature difference of wick and glass cover of the modified still, resulting in higher evaporation rate.

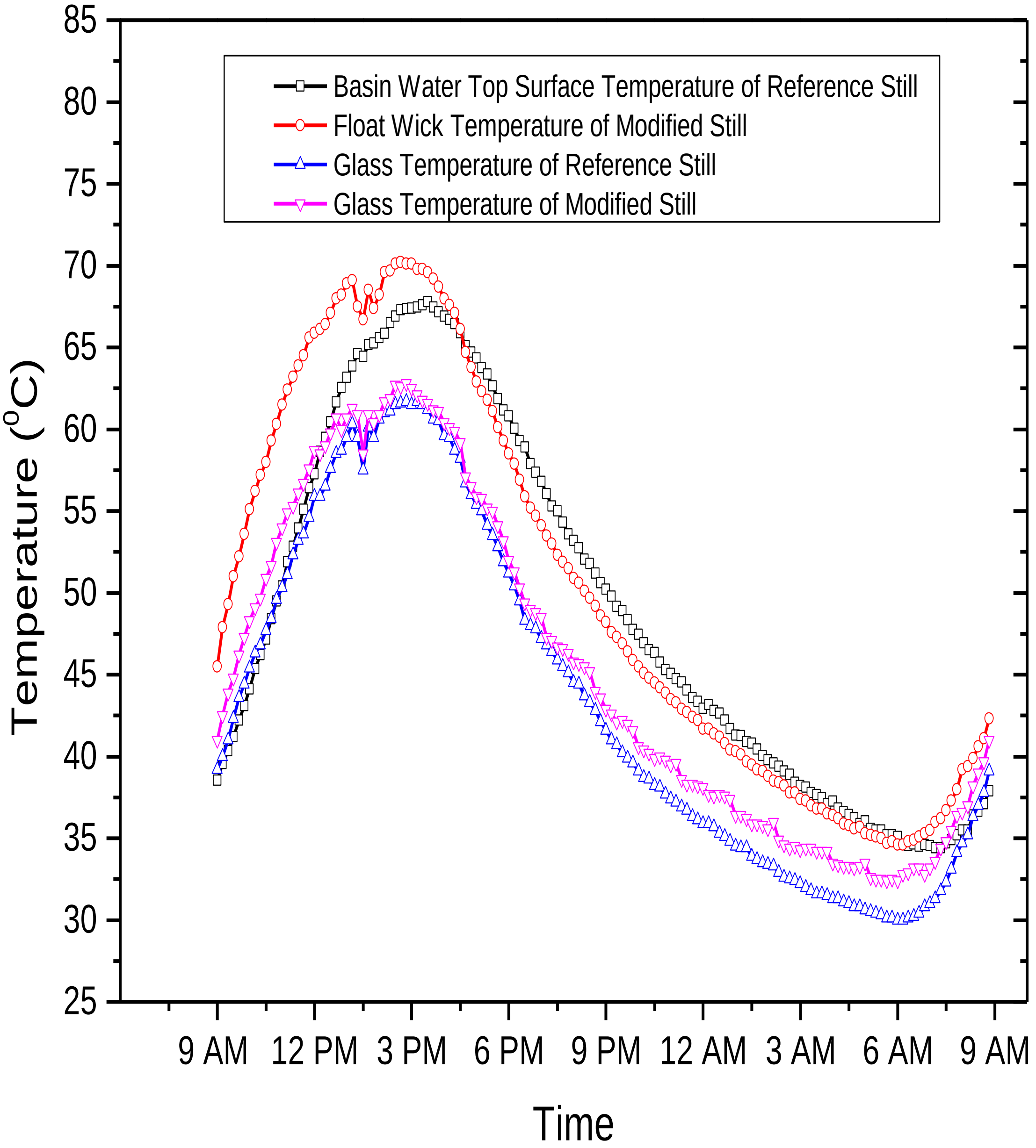

Figure 4.14. Variation of component temperatures of reference and modified stills

The hourly variation of cumulative distillate output of both the stills is shown in Figure 4.15. It is found that cumulative productivity of modified still is higher than that of the reference still. The reason behind the better performance of modified still is decreased thermal capacity of the basin due to use of float wick leading to higher operating temperature of evaporating surface which increased evaporation rate and hence improved the distillate output of the modified solar still. Significant amount of nocturnal distillate output is obtained in modified still as basin is partially covered with wick due to which heat can directly flow from warm basin water to float wick. The overall daily productivities of both reference and modified stills were 2.74 kg/m^2 and 3.31 kg/m^2 respectively.

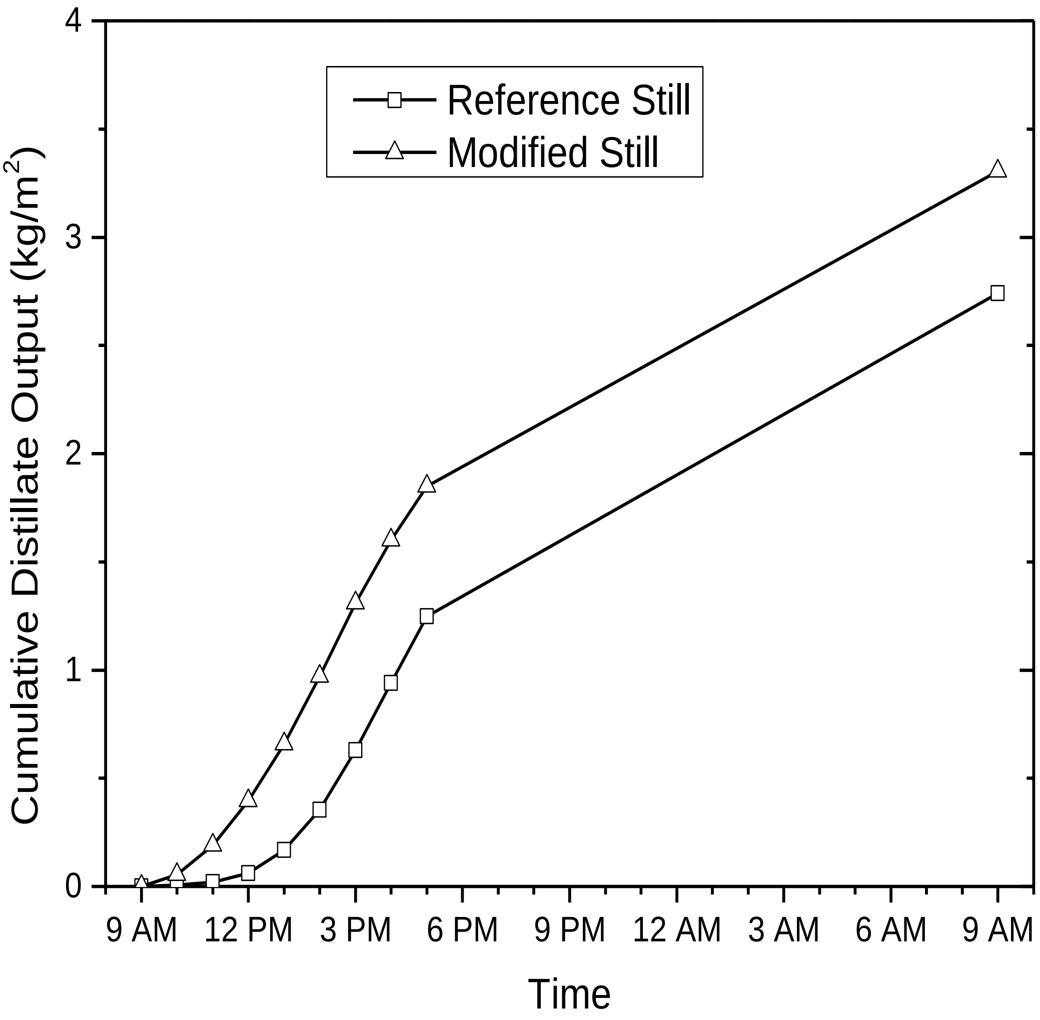

Figure 4.15. Cumulative productivity of reference and modified stills for 24 hours (9:00 AM to 9:00 AM)

4.6 Effect of varying basin water depth:

The variation of gain in distillate output of modified still over the reference still with depth of water in the basin when 75% of the basin area is covered with float wick is shown in Figure 4.16. It can be seen that there is small decrement in productivity gain as depth of the basin changes from 5 to 6 cm, whereas after this, the gain in productivity of modified still nearly remains insignificant. The reason for this could be the lesser basin water temperature in the modified still which does not change significantly as depth varies, due to which heat losses from the basin remains constant and has negligible effect on the distillate output. The maximum gain of 20.56% in productivity of modified still is obtained at basin water depth of 5 cm. So experimental results demonstrated that productivity of the solar still having float wick in the basin is slightly influenced by depth of water in the basin.

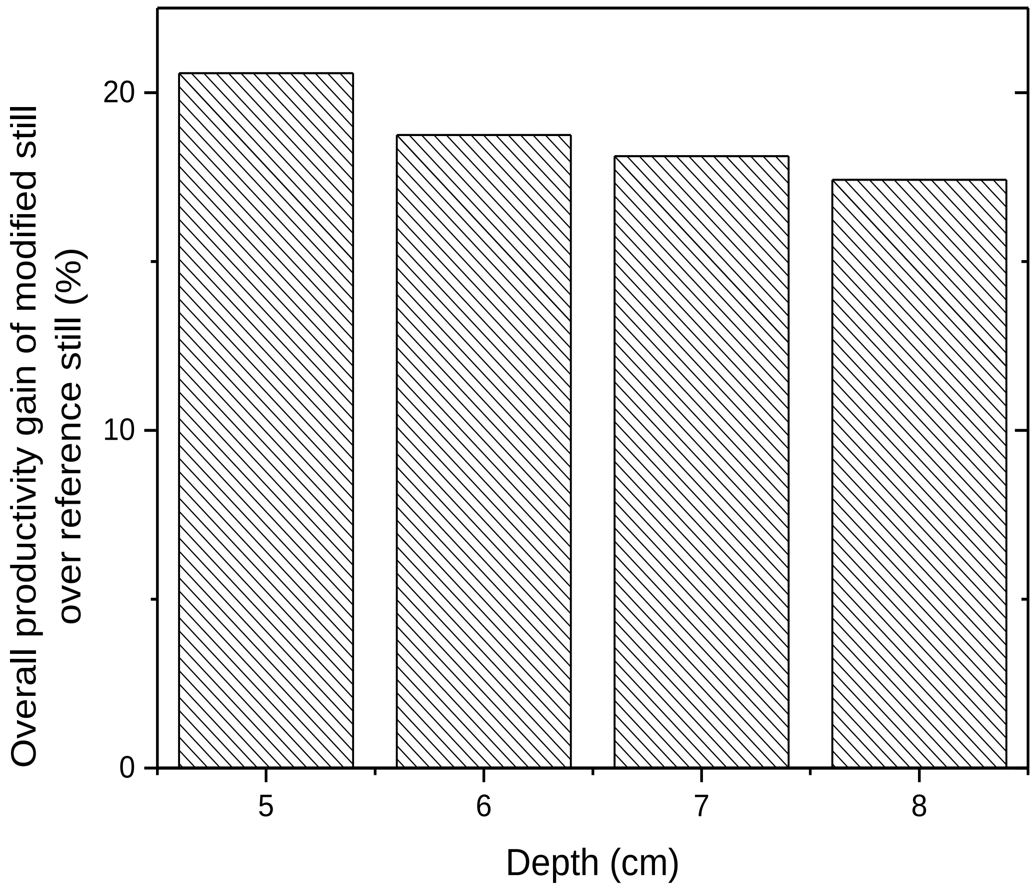

Figure 4.16. The variation of gain in productivity of modified still over reference still with basin water depth

Chapter 5

Conclusions& Future Scope

5.1 Conclusions

In the present work, conventional single slope basin type solar still has been modified by placing float wick in the basin of the still. The performance of modified still has been compared with the conventional basin type still of same dimensions under similar ambient conditions which is referred as reference still in this study. The effect of covering evaporating surface area of the basin in different proportions with float wick has been investigated. The variation of cumulative distillate output, temperatures of various components of stills, productivity gain of modified still over the reference still have been analyzed. The effect of varying basin water depth on productivity gain of modified still over reference still has also been studied. The experimental work conducted in this work lead to following conclusions:

- The float wicks reduced thermal inertia of the basin leading to early response which resulted in enhanced distillate outputs of the modified still during day time as compared to the reference still.
- The temperature difference between float wick and glass cover of modified still was more than that of water-glass cover temperature difference of the reference still, resulting in higher evaporation rate in case of modified still leading to higher distillate outputs.
- The maximum gain of 48.11% in day distillate output of modified still over the reference still was obtained when 75% of the evaporating surface area was covered with the float wick.
- The maximum decrement of 20.08% in nocturnal productivity of modified still over the reference still was reported when complete basin area of the modified still was covered with float wick.
- The maximum overall daily productivity gain of 20.56% was obtained for modified still over reference still when 75% of the basin surface area was covered with float wick.
- The basin water depth within range of 5 cm to 8 cm has very negligible effect on distillate output of the modified still. Hence, modified still can be operated at higher basin depths.

- The overall daily distillate outputs of both reference and modified still, when 75% evaporating surface area of modified still was covered with float wicks were 2.74 kg/m^2 and 3.31 kg/m^2 respectively.

5.2 Future Scope

The main drawback of solar still is its low productivity and efficiency. Many researchers have tried to improve the performance of the solar still by using various techniques which have been discussed in the literature review. Based on this study following future work in area of solar stills is recommended:

- Research could be conducted to find out optimum dimensions of float wicks that can be used in the basin of the still to yield maximum distillate output.
- There is need for development of software in order to model and simulate solar stills to study the effect of various parameters affecting the performance of solar still.
- 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 nowadays.

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