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Experimental Investigation of the Effect of Basin angle on the Performance of stepped solar still coupled with parabolic concentrator

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Abstract: Water is one of the prime elements responsible for life on the earth. It covers three-fourth of the surface of earth. However most of the earth's water is found in oceans which contain too much salt and cannot be used for drinking. Also the remaining minor part of fresh water, excluding glaciers, ice caps available on earth suitable for human requirements is getting polluted. In the present work it is suggested to purify the water using solar energy, which is available abundantly at free of cost. The device that purifies through evaporation with solar heat an energy source is known as solar still. Solar still is a simple device that purifies the water which is eco-friendly and economical. The performance of solar still depends on the rate of evaporation. Any attempt that improves the evaporation rate results in improvement of the performance of solar still. In the present attempt it is proposed to analyze the performance of single stepped solar still associated with parabolic concentrator which increases the feed water temperature and in turn evaporation rate. From this experiment it is obtained that the stepped solar still yields the maximum productivity when it is placed at the inclination (α) 12^0. Orientation of both stepped solar still basin and parabolic concentrator is also suggested to position in North-South direction to obtain maximum productivity.

Key words: Stepped solar still, parabolic concentrator, water purify.

I. INTRODUCTION

People can survive for day, weeks or months without food, but cannot live for more than a week without water. The body use water for digestion, absorption, circulation, transporting nutrients, building tissues, carrying away waste and maintaining body temperature. The average adult consumes about 2.5 to 3 liters of water per day to drink. Today fresh water demand is increasing continuously because of the industrial development, intensified agriculture, improvement in standard of life and increase in the world population. Only 3% of total water is potable but this amount is also evenly not distributed over the earth. Lack of fresh water is a prime factor in inhibiting regional/economical development. Often, water sources are brackish/containing harmful bacteria, therefore cannot be used directly for drinking purpose. The oceans constitute an inexhaustible source of water but are unfit for human consumption due to their salt content in the range of 3% to 5%. In addition, there are many coastal locations where seawater is abundant but potable water is not available. Therefore it is an urgent need for clean and pure drinking water in many countries.

A solar still is one of the solutions for purifying the brackish (more saline than fresh) and underground water. It is a highly promising and an environment friendly technology. It produces distilled water which can be used as potable water for drinking and other purposes. The performance of solar still can be improved by incorporating a modification of using parabolic solar concentrator in addition to solar still.

II. EXPERIMENTAL SETUP

In the present it is proposed to incorporate parabolic concentrator with solar still. The water initially gets heated by passing through the parabolic concentrator before getting in to solar still, therefore the performance of solar still increases.

A. Parabolic concentrator

It is a device which heat up water with solar energy. It is designed in parabola shape, it consists of mirrors to reflect the sun light towards a particular point it should be designed in such a way. A pipe is to be fixed at that particular point light which is reflected from mirror has to fall on the pipe. We used copper metal pipe, because it absorbs more amount of heat when compared to other metals.

Two valves are provided to the copper pipe to control the flow rate one is at inlet and the other is at out let. At inlet we had place a thermometer to know the inlet temperature of the water, on other side i.e., at outlet a pressure gauge and thermometer is fixed to know the how much of heat is absorbed by water and by what pressure the water is coming out from the pipe.

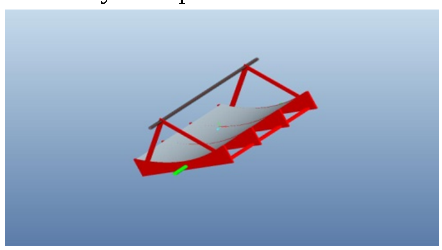

Fig 1 : Design of trough in PRO-E

This parabolic concentrator is kept in east-west direction facing towards north side, it give more effective temperature than remaining faces. The water coming from the outlet will be up to 50^0 C based on the surrounding temperature and water inlet temperature. If the temperature of inlet is less the outlet temperature is also less, because the water in the pipe flows constantly hence the temperature rises up to certain temperature.

B. Stepped Solar still

This solar still consists of manly 5 parts

1) Glass
2) Rubber seal
3) Black metal sheet fabricated into steps
4) Rectangular metal tub and
5) Wooden box

C. Glass

A glass frame is used in stills. Even plastic materials also used but plastic degrades in long term due to UV rays coming from sun. it gets difficult for condense water on it, for that purpose we used glass having thickness of 0.5 cm with dimensions 110 cm * 58 cm. when light falls on it gets heated and remaining light is transferred through the glass.

D. Rubber seal

It is placed in between glass plate and wooden box; it acts as a mediator and opposes leakage of hot water from the still. We are using rubber because it sustain to all temperatures and pressures even it seal air and vapour.

E. Steps metal sheet

In this project galvanized iron sheet is used in form of steps. The area exposed to sunlight is effectively more than other existing

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models like flat, trays etc., the contact of water with the sheet is more in area so the rate of evaporation is high hence water vapour is also high.

F. Rectangular box

It is the place where steps are placed. We proved thermacol pieces under the steps they act as insulators and opposes heat from getting out from box. At one end of the box a hole is driven for getting water into the box. At other end on left corner of this end a hole is driven for outlet of waste water.

G. Wooden box

Entire apparatus is kept in this wooden box, we select wooden box because it is insulated and it didn't transfer heat through it. It also provided holes at the respective places same as rectangular box.

H. TDS Indicator (Total Dissolved Salts)

TDS is a device which is used to know the ppm of water, ppm value of a general water is 225 -235. For the purified water ppm level is below 40, the minerals in such type of water are good and healthy to humans.

This setup consists of mainly 2 parts

1) Parabolic concentrator and
2) Stepped Solar still

The top side to pour water it acts as an inlet and at the bottom placing a hole having diameter of 3 cm. From the bottom a pipe is attached between tank and to parabolic concentrator, the pipe which is used to join the tank and concentrator is surrounded with a black tape to absorb heat from the sun. The capacity of the tank is up to 15 liters.

Fig 2: Experimental Setup of Stepped solar still with parabolic concentrator

III. WORKING PROCEDURE

A. With Parabolic Concentrator

1) Firstly 3000 ml of hard water which is at normal atmospheric temperature of 255 PPM is taken in the storage tank which is placed at a height of 200 cm from the ground.
2) From the bottom of the tank a pipe is passed to the parabolic concentrator which contains a regulating valve to control the inlet water flow from the tank into the parabolic concentrator.
3) Parabolic concentrator is kept at North face direction kept in such a way that the maximum reflected sun rays falls on the concentrator pipe.
4) The flow rate of water is maintained with the help of the regulator in such a way that the water obtained at the both outlets (wastage water & pure water) is equal to inlet water.
5) The concentrator should be maintained in such a manner that the reflected sun rays has to fall on the copper pipe. At the inlet of concentrator a thermometer is placed to know the inlet temperature of the water which is coming from water tank, it should be at surrounding temperature. Again at the outlet of parabolic concentrator another thermometer is placed to know the outlet temperature of the water which is coming out from the copper pipe. The outlet temperature of the water depends upon various parameters like

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inlet temperature and atmospheric temperature.

6) This preheated water is sent into the solar still with the help of pipe.

When the water enters the stepped solar still basin the water flows on steps uniformly. As the stepped solar still is coated with black die, stepped solar still basin gets heated up by the trapped sunlight. The surface of the stepped solar still is heated up and additionally the preheated water from the parabolic concentrator is allowed to pass on the steps of the basin. As a result the temperature of the water reaches the evaporation temperature quite quickly and results in evaporation of water from the step surface. As by using steps it results in effective heat absorption and evaporation of the water thereby forming vapour. These vapour particles settle on inner side of the glass surface. As the amount of water vapour collected on the inner surface of the glass increases small water droplets roll down along the inclined glass surface and is obstructed by the stopper attached to the glass. Now the water droplets of distilled water get collected in the collector.

For the experimental purpose at initial to know the productivity of this solar still it is kept at the angle of 12^0 with an inlet temperature at morning session from 9AM to 10AM is 35^0C having 225ppm. At these parameters the productivity of distilled water is 92 ml. It is directly proportional to the temperature of atmosphere. I.e. if the inlet temperature and sunlight radiation increases productivity also increases with respect to time. At 1PM to 2PM the temperature of the atmosphere is 35^0C .At an inlet temperature of 48^0C. It is observed that the maximum effective in the production is noted at this time which is equal to 176ml. This is because of sun is very nearer to the earth than compared to other times. Later the radiation of the sun goes on decreasing based on that the productivity of the solar still also decreases towards the evening session.

The next day i.e. 7 Feb 2015 in order to know the optimum angle it is changed to 15^0 from 12^0. Water PPM is 225 as that of previous day i.e. 6^{th} Feb. 2015. With the atmospheric temperature 37^0C water is sent to parabolic concentrator from the tank with an initial temperature of 27^0C. At the out let of the concentrator the temperature is noted as 33^0C. This is sent to solar still which is kept at the angle of 15^0. From 9AM to 10AM the distilled water which is collected is equal to 61ml and is goes on increasing towards the afternoon session at 2PM to 3PM. We got maximum productivity of 155ml with inlet water temperature at 42^0C.

On 8^{th} Feb. 2015 at 18^0 inclination angle with water PPM is 225. With the atmospheric temperature 38^0C water is sent to parabolic concentrator from the tank with an initial temperature of 31^0C. At the out let of the concentrator the temperature is noted as 36^0C. This is sent to solar still which is kept at the angle of 18^0. From 9AM to 10AM the distilled water which is collected is equal to 59ml and is goes on increasing towards the afternoon session. At 12PM to 1PM maximum productivity of 110ml with inlet water temperature at 49^0C as shown in the table.

On 9^{th} Feb. 2015 at 20^0 inclination angle with water PPM is 225. With the atmospheric temperature 38^0C water is sent to parabolic concentrator from the tank with an initial temperature of 29^0C. At the out let of the concentrator the temperature is noted as 35^0C. This is sent to solar still which is kept at the angle of 20^0. From 9AM to 10AM the distilled water which is collected is equal to 22ml and is goes on increasing towards the afternoon session at 1PM to 2PM. We got maximum productivity of 48ml with inlet water temperature at 48^0C.

The initial water PPM which is taken is 235 PPM as indicated in the TDS (total dissolved salts) indicator.

Various experiments are also done on the setup by changing the orientation of both parabolic concentrator and stepped solar still basin:

B. Without parabolic concentrator

Fig 3 : Experiment setup without parabolic concentrator

It is clearly observed that the maximum effective productivity is obtained when the stepped solar still is placed at an angle of 12^0.In order to find the productivity of still by removing the parabolic concentrator. To know the maximum efficiency without parabolic concentrator the still is placed at 12^0 inclination, because the maximum productivity will be obtained at 12^0 in the North-South direction facing towards the North. This the experiment the system consisting of parabolic concentrator

This setup consists of 2 parts. They are:

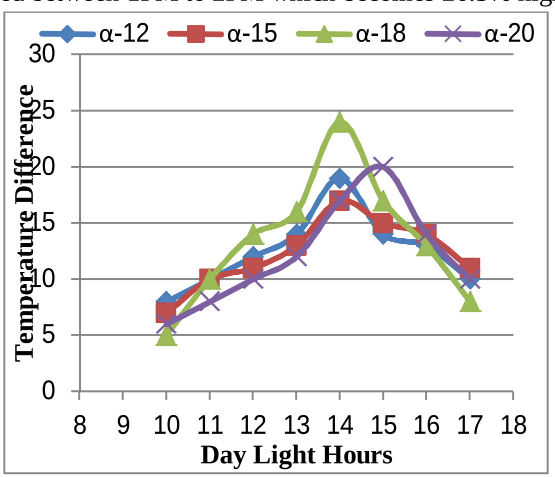
1) Water tank
2) Stepped solar still basin

C. Working procedure

On 8^{th} Feb. 2015 at 18^0 inclinations angle with water ppm is 225. With the atmospheric temperature 35^0C water is sent to stepped solar still from the tank with an initial temperature of 31^0C. This is sent to solar still which is kept at the angle of 12^0. From 9AM to 10AM the distilled water which is collected is equal to 64ml and is goes on increasing towards the afternoon session at 1PM to 2PM maximum productivity of 107 ml. As water needs to heated only after it enters in to the stepped solar still basin, water takes more time to heat when compared to that of experimental setup connected to the parabolic concentrator. When the water gets heated then it vaporizes and vapour forms on the inner side of the glass. As the cool air is passed on to the upper side of the glass plate the vaporized water converts into droplets and scroll down along the glass plate and the pure water is collected in the concentrator. Various observations are made.

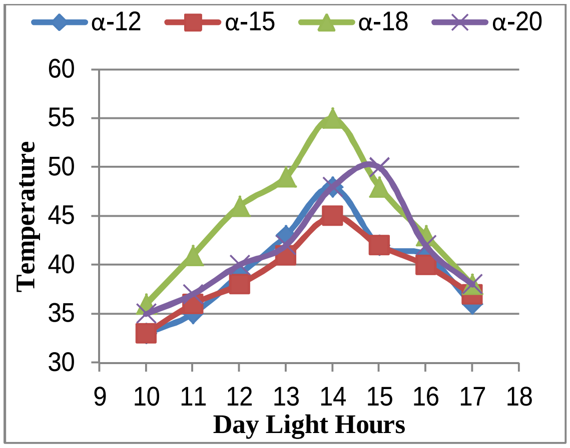
IV. RESULTS & DISCUSSIONS

Graph 1 shows the effect of day light hours on the temperature difference of parabolic concentrator between inlet and outlet for different basin angles of solar still. It is observed from the graph that as time progress temperature difference increases initially up to the time ranging from 12:00PM to 2:00 PM and decreases thereafter for all considered basin angles of solar still. A maximum temperature difference of 19^0C, 17^0C, 24^0C and 20^0C are obtained for corresponding basin angle (α) of 12^0, 15^0, 18^0 and 20^0. Initially at morning sessions from 8AM to 10AM the temperature difference for both angles $\alpha = 15^0$ and 18^0 is nearly equal. This temperature difference gradually increased between 1PM to 2PM which becomes 26.3% higher than 15^0 inclinations.



Graph 1: Effect of daylight hours on temperature difference for different basin inclination of solar still.

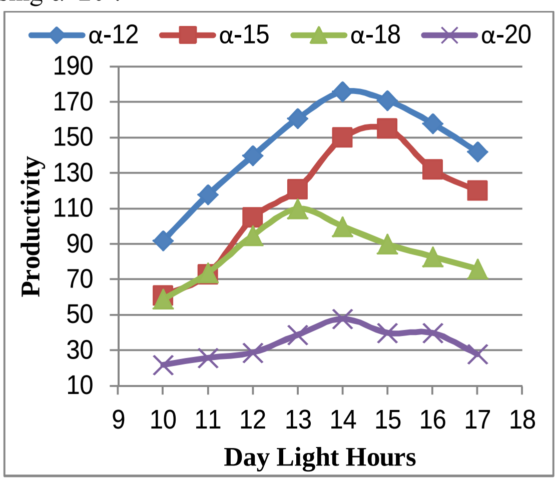
Graph 2 depicts the effect of day light hours on the temperature of parabolic concentrator at the outlet with various inclination angles (α) of 12^0, 15^0, 18^0 and 20^0 .It is observed from the graph that as time progress temperature from 12 to 2 pm increases and decreases thereafter. The maximum temperature is noted as 55^0during 1pm to 2pm. When compared to forenoon session i.e. from 9 to 10 AM, the productivity is 52% higher during 1pm to 2 pm. The maximum temperature difference obtained is 24^0c between 1pm to 2pm using 12^0 basin angle because rays from the sun are more direct i.e. the sun rays are at highest angle to the ground [i.e 90^0c] during this time and also the surrounding atmosphere gets heated till from the morning and all together results in effective performance of parabolic concentrator.



Graph 2: Effect of daylight hours on temperature for different basin inclination of solar still

Graph 3 depicts that effect of daylight hours on productivity at various values of angle α= 12^0, 15^0, 18^0 and 20^0 .It is observed that when inclination angle is 12^0 the maximum productivity is obtained i.e. 176ml between 1pm to 2pm in the direction, because the amount of water stored on steps at this respective angle is maximum and the intensity of sun light is maximum at this duration of time. it is found that as basin angle increases the productivity decreases.

Also it is observed that basin angle, α > 18^0 results in poor performance of solar still. The maximum productivity for α = 12^0 is 47.7% higher than that of productivity using α=20^0.



Graph 3: effect of daylight hours on the productivity for different inclination on solar still

Graph 4 shows the relation between time of the day (hrs) and distillate yield for solar still. Productivity taken at α = 12^0, 15^0, 18^0 and 20^0 .On a typical day, the distillate yield obtained for solar still α =$12^0$and α=20^0 is observed to be 1164 ml and 272 ml during the period from 9am to 4 pm with 5 mm glass cover thickness of solar still, the distillate yield for α =12^0 increased by 892 ml which is 4.5 times (23%) than the angle α =20^0. When the inclination is α =20^0 water doesn't stay for a long time on the steps of the basin as a result of reduced in productivity (272 ml). when the angle is reduced to α =12^0 then more water is stable on the steps and due to which water is vapourised uniformly resulting higher yield of the distillate water i.e. 1164 ml. Hence α =12^0 is the optimum inclination to obtain maximum productivity from the solar still.

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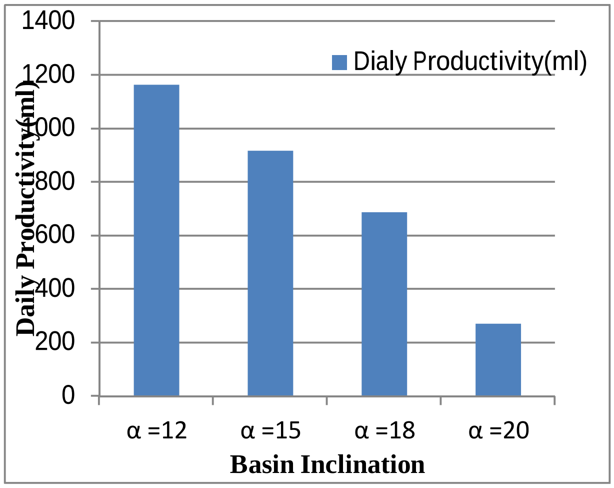
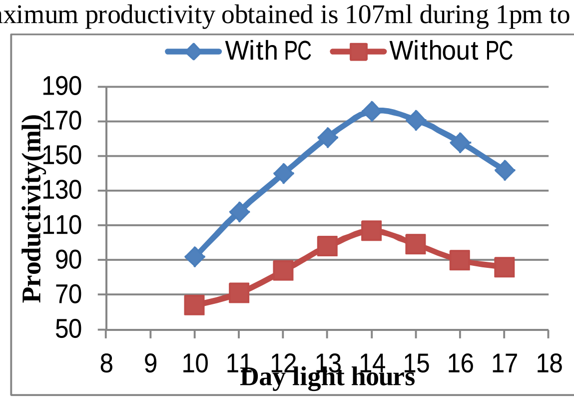


Graph 4: Effect of basin inclination on the productivity

Graph 5 depicts the daily hour on the productivity firstly with and without parabolic concentrator. Using parabolic solar concentrator, it is observed that productivity is 92ml at morning 9AM to 10 AM which is minimum and the productivity of 176 ml which is maximum and obtained during 1pm to 2pm. It is because in earlier hours of the day i.e. 9am to 10am the sun rays are not so effective that fall on the solar still basin and also it need some time . Lesser sun rays are reflected by the concentrator to the heating pipe and also it need some time initially for the entire set up to get warm and there after water starts heating and vaporization process begins hence temperature difference is less as a result water in the still also gets heated slowly so the hourly productivity is reduced.

In case of 1pm to 2pm enormous sun rays strike the parabolic concentrator as a result increasing the temperature difference by 45% in parabolic concentrator leading to higher evaporation of water in basin results in higher productivity of 176 ml at inclination α $=12^0$.

In absence of parabolic concentrator water entered in the still needs to be heated. More time is consumed in order to absorb the radiations. The output of the water from the solar still without parabolic concentrator is reduced by 64.5% to that of the system using a parabolic concentrator. The maximum productivity obtained is 107ml during 1pm to 2pmwithout solar concentrator.



Graph 5: effect of daylight hours on productivity with and without parabolic concentrator

Graph 6 shows the effect of daily light hours on productivity by solar still orientation. It is clear that productivity is maximum when the solar still is placed in North-South direction. The maximum productivity is obtained at 1pm i.e. 176 ml. North-south direction is optimum because sun moves in the direction of East-West hence the sun rays continuously fall on the solar concentrator and on steps of solar still basin. At 4pm the productivity is reduced by 24% to that of maximum where as it is 33 % less during 9am to

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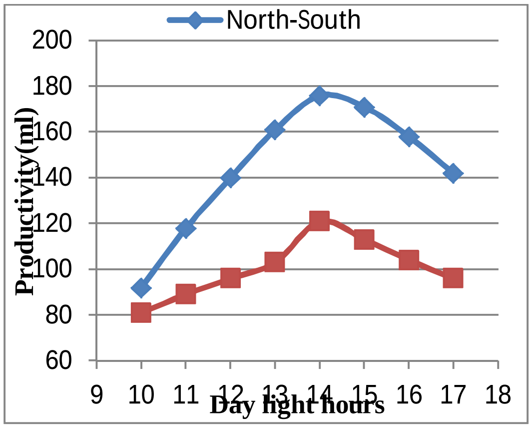
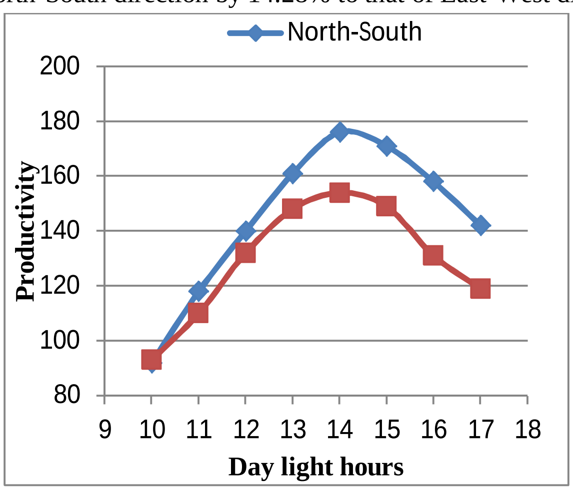
10am. Though the sunray effect is almost the same during the both times the performance of solar still is superior at 4Pm because the atmosphere stores the heat of the sun there by causing the water on steps to evaporate. The still positions need not to be changed frequently if it is placed in North-West direction.

When the still is placed in East-West direction only at the morning hours [i.e. 9am to 1pm] the sun rays fall directly on the steps of basin. Later sun position is changed due to East due to which basin cannot receive sun rays directly resulting in lesser productivity. When kept in North-South direction the productivity is 45% higher than that of East-West direction.



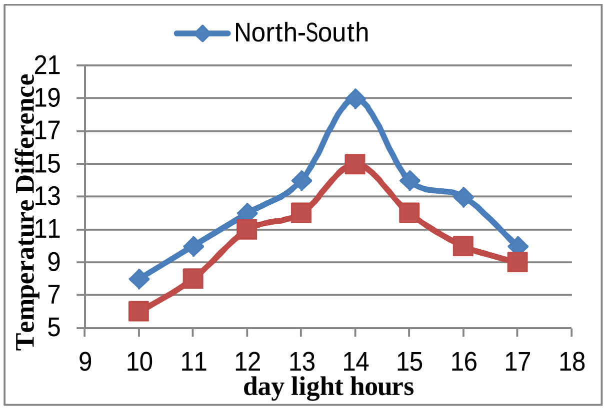
Graph 6: Effect of daylight hours on productivity due to effect of solar still orientation

Graph 7 shows the effect of daily hour productivity due to effect of parabolic concentrator orientation. It is observed that when parabolic concentrator is placed in North-South direction then sun rays fall on concentrator uniformly until the sun set. Effective heating of the pipe of concentrator takes place. Day wise productivity for solar still placed in North-South direction is 45% higher for concentrator placed in North-South direction than that of East west direction. Day wise maximum productivity is 1158 ml for North-south direction of both concentrator and basin. Day wise maximum productivity for East-West direction of concentrator and North-south direction of basin is 803 ml. Earlier in the morning sessions from 9AM to 10AM productivity for both North-South and East-West orientation of the concentrator the productivity is likely to be equal. But at afternoon hours from 1PM to 2PM the productivity is more efficient for the North-South direction by 14.28% to that of East-West direction of the concentrator.



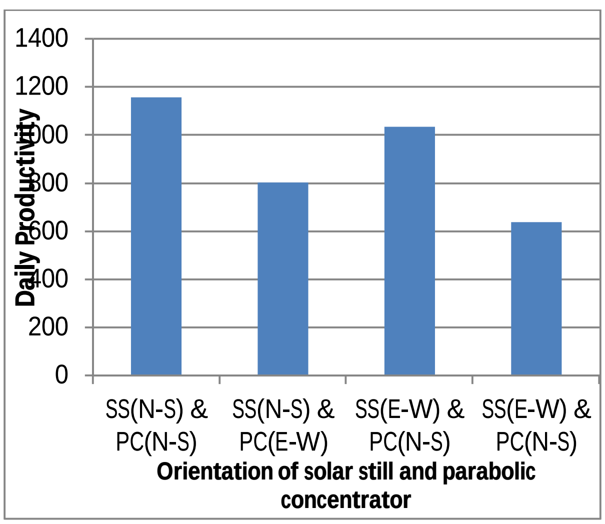
Graph 7: Effect of daily hours on productivity due to effect of parabolic concentrator orientation

Graph 8 shows the effect of daylight hours with effect of parabolic concentrator on temperature difference. From the graph it is observed that as time proceeds the temperature difference increases and also it is observed that increase in temperature difference is slow in the forenoon and attains peak in the mod afternoon during which it takes rapid increase and in the afternoon the drop of temperature difference is very slow because the surrounding atmosphere is already gets warm-up. Maximum temperature difference [19^0C] at 1pm is observed when the parabolic concentrator is placed in North-South direction. When the parabolic concentrator is placed in East-West direction the maximum temperature difference [15^0C] at 1pm is observed. The parabolic concentrator is 27% greater efficient when placed in North-south direction than that of East-West direction.



Graph 8: effect of daylight hours with effect of parabolic concentrator on temperature difference

Graph 9 shows the effect of orientation of solar still and parabolic concentrator on daily productivity. Various orientations are considered for both parabolic concentrator and solar still basin. Firstly both concentrator and solar still are placed in North-south direction getting maximum daily productivity of 1158 ml. when solar still is placed at North-South and solar concentrator at East-West direction the daily productivity obtained is 803 ml. when solar still is placed at East-West and solar concentrator at North-South direction the daily productivity obtained is 1036 ml. when solar still is placed at East-West and solar concentrator at North-South direction the daily productivity obtained is 640ml. overall the efficiency of both solar still and solar concentrator is maximum when they are place in North-South direction getting a daily maximum productivity of 1158 ml. It is optimum position for both because the sun moves along the path East-West. In North-South direction solar concentrator and solar still basin receives maximum solar rays without frequent changing the positions. This optimum position is 45% than all the respective positions.



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Graph 9: effect of orientation of solar still and parabolic concentrator on daily productivity

V. CONCLUSIONS

After conducting performance evaluation tests on solar still by varying basin angles, also with and without parabolic solar concentrator the conclusions are summarized as follows:

Productivity of distilled water increases with decrease of basin angle (α) and the 12^0 basin angle is the optimum angle in getting better performance of solar still that results a maximum day productivity of 1164 ml.

The performance of the solar still integrated with the parabolic solar concentrator provides better performance compared with the still without integration. The productivity is 64 % higher by integrating parabolic solar concentrator than that of the productivity without solar concentrator.

Distilled water productivity is superior during 1PM to 2PM than that of productivity either in the morning or in the afternoon period. The productivity during 1PM to 2PM is 1.96 times higher than that of productivity during 9AM to 10Am and is 1.12 times higher than that of productivity during 3PM to 4PM.

Daily productivity of distilled water is maximum when solar still is placed at North-South direction getting maximum daily output of 1164 ml. During 1PM to 2PM at an angle of $\alpha=12^0$[176 ml] which is 68.75% higher than that of still while placed at East-West direction where productivity is observed as 121 ml.

When the orientation of parabolic concentrator is at East-West direction then lesser productivity is obtained i.e. 154 ml from 1PM to 2PM. whereas when the orientation of parabolic concentrator is changed to North-South direction maximum productivity is obtained at 1PM to 2PM as compared to earlier orientation of concentrator. The maximum productivity of distilled water at North-South direction during time period 1PM to 2PM is 176 ml which is 14.28% more than East-West direction of the parabolic concentrator. North-South orientation of parabolic concentrator with North-South orientation of solar still is the optimum combination that results in higher productivity.

Temperature differences in the solar concentrator are observed for various inclination $\alpha= 12^0$, 15^0, 18^0 and 20^0 of the basin. Temperature difference is maximum at an inclination of $\alpha= 18^0$. Maximum temperature difference obtained is 24^0C at $\alpha= 18^0$ which is 20% higher than the temperature difference obtained at $\alpha= 15^0$.

When the parabolic concentrator is at East-West direction concentrator is less effective as it can be determined by the maximum temperature difference obtained which is 15^0C whereas when its orientation is changed to North-South direction its effectiveness improves due to resultant maximum temperature difference obtained here is 19^0C which is 26.6% higher effective than East west direction. It is observed that the ppm of water which is collected at the outlet of still is 38 whereas the ppm of water at the inlet is 225.The general water is distillated with this experiment.

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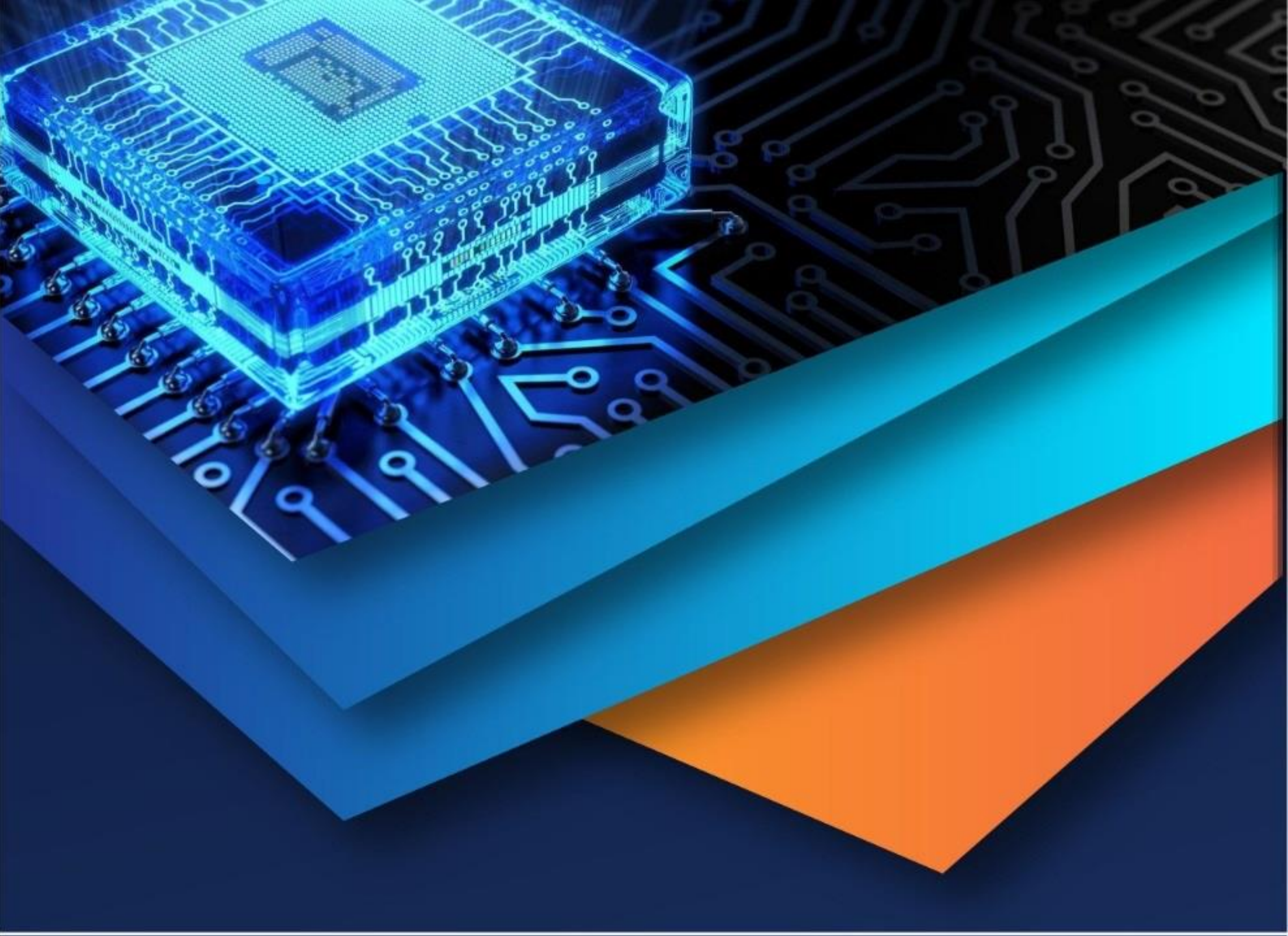

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