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Experimentally Investigating the Effect of Basin Water Depth in Passive Pyramid type Solar Still

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***Abstract:** This study is aiming to investigate experimentally the effect of basin water depth on the productivity of passive pyramid type solar still at Indore city of M.P(INDIA) with latitude and longitude (22.7196°,75.8577°). Solar still is very promising solution to address the scarcity of fresh water globally. So, understanding the role of parameter that affects its performance is very important in order to increase its productivity and efficiency, for that we construct a passive pyramid type solar still with square base and tested under varying depth from 2 cm to 10 cm. To evaluate its internal heat transfer and productivity. Temperature profile of ambient air, basin water, basin liner and glass cover also recorded to understand the heat transfer. While operating it with 2cm basin water depth the output distillate is (1020ml). While with 4 cm,6cm,8cm and 10 cm are 860,695,565 and 490ml. Which shows that its productivity is inversely proportional to the basin water depth. Because shallower water depth improves its productivity by faster evaporation. Whereas deeper basin water depth has lower efficiency due to its high thermal inertia. The conclusion of this experiment shows significant statement into the optimal design of the passive pyramid type solar still. This study highlights the importance of basin water depth as a critical parameter of passive solar still, which lay practical recommendation for future research work in solar base desalination system.*
***Keywords:** Solar desalination, passive type solar still, Basin water depth, Heat transfer coefficient, Distilled water.*

t:	Time interval in (sec).
$I(t)$:	Solar Intensity in (W/m^2).
T_a:	Ambient temperature in (°C).
T_g:	Glass cover temperature in (°C).
T_w:	Basin water temperature in (°C).
T_b:	Basin liner temperature in (°C).
A_b:	Surface area of basin liner (m^2).
P_w:	Partial saturated vapor pressure at a basin water temperature (N/m^2).
P_g:	Partial saturated vapor pressure at a glass cover temperature (N/m^2).
h_{cwg}:	Convective heat transfer coefficient from basin water to glass cover (W/m^2 °C).
h_{ewg}:	Evaporative heat transfer coefficient from basin water to glass cover (W/m^2 °C).
h_{rwg}:	Radiative heat transfer coefficient from basin water to glass cover (W/m^2 °C).
h_{twg}:	Total heat transfer coefficient from basin water to glass cover (W/m^2 °C).
q_{cwg}:	Convective heat transfer from basin water to glass cover (W/m^2).
q_{ewg}:	Evaporative heat transfer from basin water to glass cover (W/m^2).
q_{rwg}:	Radiative heat transfer from basin water to glass cover (W/m^2).
q_{twg}:	Total heat transfer from basin water to glass cover (W/m^2).
L_{ev}:	Latent heat of vaporization of water (J/kg).
M_w:	Hourly distillate output per unit basin area (Kg/m^2/h).
M'_w:	Daily distillate output per unit basin area (Kg/m^2/d).
ε_g:	Emissivity of glass cover.
ε_w:	Emissivity of basin water.
ε_{eff}:	Effective emissivity between water surface and glass cover.
σ:	Stefan–Boltzmann constant (W/m^{2}k^4).
η:	Efficiency of solar still.

Subscripts

a:	Ambient
b:	Basin liner.
c:	convective.
e:	evaporative.
g:	Glass cover.
r:	radiative.
w:	Basin water.

I. INTRODUCTION

Access to clean and safe drinking water is a fundamental human need, yet millions of people worldwide face water scarcity due to population growth, industrialization, and climate change. Traditional water purification methods often require significant energy inputs and infrastructure, making them inaccessible to remote and resource-limited communities. In this context, solar desalination has emerged as a sustainable and cost-effective solution, leveraging renewable solar energy to produce freshwater from saline or brackish water sources. Among various solar desalination technologies, solar stills have gained attention for their simplicity, low maintenance and ability to operate in off-grid locations.

Both types of water (Saline and Brackish water) highlight the importance of desalination technologies in addressing freshwater scarcity. While emphasizing the need for sustainable management to mitigate environmental impacts.

Solar stills function on the principle of evaporation and condensation, where solar radiation heats the water in a basin, causing it to evaporate. The vapor then condenses on a cooler surface, typically a glass cover and is collected as distilled water. The performance of solar stills depends on several factors, including climatic conditions, design parameters, and operational variables. One critical design parameter is the depth of water in the basin, which directly influences the rate of evaporation, heat storage capacity, and overall efficiency of the system. While deeper water layers can store more thermal energy, they also increase the thermal inertia, potentially reducing the daily productivity of the still. Conversely, shallower water depths facilitate faster evaporation but may limit the total amount of water processed.

The pyramid solar still, a variant of the conventional single-slope still, offers several advantages, such as a larger condensing surface area and better exposure to solar radiation. However, the relationship between basin water depth and the performance of passive pyramid solar stills remains underexplored, particularly in experimental studies. Understanding this relationship is crucial for optimizing the design and operation of solar stills to maximize freshwater yield and efficiency.

II. OBJECTIVE

This study aims to experimentally investigate the effect of basin water depth on the performance of a passive pyramid solar still. By varying the water depth and analysing the system's productivity, thermal behaviour and efficiency, the research seeks to identify the optimal water depth for enhanced performance. The findings will contribute to the growing body of knowledge on solar desalination technologies and provide practical insights for designing efficient and sustainable water purification systems. Ultimately, this research aligns with global efforts to address water scarcity through renewable energy-driven solutions, offering a pathway to improve access to clean water in underserved regions. By harnessing the sun's energy, solar distillation offers a lifeline to communities without access to advanced technology, proving that nature itself can help solve water challenges.

III. LITERATURE REVIEW

Solar desalination has emerged as a sustainable and cost-effective solution, leveraging renewable solar energy to produce freshwater from saline or brackish water sources. Among various solar desalination technologies, solar stills have gained attention for their simplicity, low maintenance, and ability to operate in off-grid locations.

But on other hand, the productivity of solar still is low when we compare to other techniques especially passive solar still. To increase its productivity and efficiency many research work is being carried out. [1] compare the conventional single slope solar still with octagonal shaped solar still and found that this innovative design outperformed with conventional one. When operating under several operating conditions. [2]their findings emphasize optimizing water depth, water inlet temperature, and structural enhancements like fins to improve solar still efficiency, aiding the design of sustainable desalination systems. [3] they use sand as a thermal energy storage material to increase the productivity of a pyramid solar still. [4]compare the performance and efficiency of pyramid solar still in active and passive mode.

In active mode they use solar water heater notably with spiral and straight tube design. [5]their study focusing on using graphene oxide (GO) with the Ø= 0.2, 0.4 and 0.6 wt.% dispersed in paraffin, as phase-change materials (PCMs), to improve the productivity of a solar still for desalination applications. [6]in their expirement, the effect of thermal energy storage is tested in a triangular base pyramid solar still at a constant water depth. Thermal energy storage materials used are quartz rock, mild steel and sieved red bricks . [7]in their experiment a four fold i.e, square base pyramid solar still is used for desalination with activated carbon from sugarcane bagasse as a thermal heat storage material. Along with four different insulation materials, in which polyethylene with aluminium shows the most effective insulation work due to its low emissivity with a low conductive heat transfer of .65 ± 0.44 W.

[8]their research indicates about the numbers of parameter that affect the performance of solar still. These parameters are meteorological, design and operating factors. [9]they are comparing the performance of convientitonal solar still with corrugated plate absorber plate. In solar still with corrugated absorber plate they increase the evaporation area which help in increasing the distillate. [10] they experimentally analyze the performance of pyramid solar still by maintaining constant water depth in the arid regions of Saudi Arabia.

IV. EXPERIMENTAL SETUP

Initially a box of galvanized iron sheet is setup as a water basin of predefined dimensions. The reason for selecting galvanized iron is its easily availability and its corrosive resistance behaviors although stainless steel also has corrosion resistance behavior but it is costlier as compared to galvanized iron, almost 2-3 times than galvanized iron. So, selecting G.I sheet is preferable from economical point of view.

Then the box of G.I is now black painted in order to increase the surface absorptivity because black color absorbs heat and does not allow heat to escape, so that maximum heat energy from sun is absorbed and water inside basin get heated.

Now, through holes are produced in the basin for contaminated water inlet (for desalination), hole for waste contaminated outlet and for fresh distillate output and PVC tray also installed with downward slope inside the basin for easily removal of condensate water from solar still, which is connected with a measuring jar.

Now for giving structural strength to the basin a plywood structure is used because of its light weight, good strength and easily availability. Plywood box is also painted inside and outside by black color for its longevity and increase its heat absorptivity. so, that heat losses should be minimized. All necessary holes are produced.

To avoid heat loss from basin, we use polystyrene sheet in between G.I box and Plywood box due to its economical and insulating property and all necessary holes are also produced.

Next step is to fix all box, galvanized iron, plywood box and in between polystyrene sheet as an insulating material. They all are fastened with nut, bolt along with washer for a structurally sound structure. And also take care about the hole's concentricity and leakage proof for that we use M- seal at nut and bolt.

Now it times to connects all the connections of pipes i.e., for condensate or desalinized water from basin to a measuring flask. Connection of saline or contaminated water pipe from basin wall to the tank of contaminated water, which is placed at a height in order to facilitate the gravity flow. similarly for waste or contaminated removal connection. all the flow were controlled with the help of valve for proper working.

Next step is to build condensate glass cover with an angle of 23 degree depending on the latitude of Indore for maximum irradiance on the glass cover. Also, rubber binding is done in all the four sides of condensate cover and in the G.I and plywood for preventing the vapor leakage.

Fig. 1 Pyramid type solar still for experiment.

After setting up glass cover in the basin, both are glued by glued gun in order to avoid any vapor leakage during experimental hours.

A. Dimensions of Structure

S.no	Parameters	Dimensions in m
1	Length of galvanized iron setup	0.6
2	breadth of galvanized iron setup	0.6
3	Height of galvanized iron setup	0.2
4	Thickness of galvanized iron setup	0.002
5	Length of Plywood setup	0.63
6	breadth of Plywood setup	0.63
7	Height of Plywood setup	0.2
8	Thickness Plywood setup	0.009
10	Thickness of polystyrene insulation	0.005
11	Thickness of glass cover	0.005

TABLE NO. I SHOWS THE DIMENSION OF THE EXPERIMENTAL SETUP.

The experiment is conducted in winter season a month of January, the location of the experimental setup is Indore with a latitude and longitude (22.7196°,75.8577°). The experiment is conducted to investigate the effect of water depth in the productivity of passive pyramid type solar still. For that we are operating the solar still for five consecutive days with basin water depth of (2,4,6,8 and10 cm), water used for desalination in solar still is underground water with TDS value of 1040 mg/ml. The experimental is conducted from 7:00 to 19:00 and following data is recorded

- Solar radiation
- Ambient temperature
- Glass cover temperature
- Basin water temperature
- Basin linear temperature
- Vapor temperature
- TDS of water

B. Data Analysis

Following assumption are taken care for experimental data analysis are as follows:

- Solar still is considered as a vapor leakage proof.
- Water vapor and air are considered as an ideal gas.
- Assuming there is no change of any physical properties of water with respect to temperature.
- Neglecting the heat storage capacity of glass cover and insulation material as compare to basin water.
- Assuming there is no temperature gradient in the glass cover and basin water and consider their area to be same.

Basically, in solar still there is two types of heat transfer one is internal and other is external heat transfer. Internal heat transfer includes heat transfer between inner side of glass to the basin water by three modes of heat transfer that is convection, evaporation and radiation. whereas, external heat transfer includes heat transfer between solar still surfaces (top, bottom, and side surface) and atmosphere. In this experiment we focus our analysis towards internal heat transfer only.

So, convective heat transfer take place between inner side of glass cover and basin water. Which is calculated by following equation.

where, the convective heat transfer coefficient is obtained from an empirical relation, which is given by [11]

$$h_{cwg} = 0.884\left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{(268.9 \times 10^3 - P_w)}\right]^{\frac{1}{3}}$$

The evaporative heat transfer occurs between inner side of glass cover and water surface is given as,

$$q_{ewg=}h_{ewg} \times (T_w - T_g)$$

Where evaporative heat transfer coefficient between glass cover and water surface is found from [12]

$$h_{ewg} = (16.28 \times 10^{-3}) h_{cwg} \left[\frac{(P_w - P_g)}{(T_w - T_g)}\right]$$

The radiative heat transfer occurs between any two bodies which are at different temperature. In this case the water surface and glass cover are considered as infinite parallel planes [13]. The radiative heat transfer from water surface to the glass cover is given below,

$$q_{rwg=} h_{rwg} \times (T_w - T_g)$$

And the radiative heat transfer given by Stefan Boltzmann's equation is given as,

$$q_{rwg=\varepsilon_{eff}} \sigma \left[(T_w + 273)^4 - (T_g + 273)^4\right]$$

where $\mathcal{E}_{eff}$ is the effective emissivity of water surface to the glass cover and σ is the Stefan Boltzmann's constant taken as 5.67 ×10−8 $W/m^2\ K^4$.

$$h_{rwg=\varepsilon_{eff}} \sigma \left(\frac{(T_w + 273)^4 - (T_g + 273)^4}{(T_w - T_g)}\right)$$

So, the total heat transfer coefficient between the inner glass surface and water surface by all three modes of heat transfer is given as,

$$h_{twg} = h_{cwg} + h_{ewg} + h_{rwg}$$

Now by using above assumptions and formula we were calculating the heat transfer coefficient in all the three modes i.e., convection, evaporation and radiation.

C. Instrumentation and Uncertainty.

The instruments used during the experimental process to ensure precise data collection are solarimeter, thermocouple and measuring flask.

Solarimeter: Used to record solar radiation intensity on the still's surface.

Thermocouple (Type-K): Calibrated to measure temperatures at the basin water, liner, glass cover, vapor and ambient air.

Measuring flask: A graduated cylinder for quantified hourly and daily distillate output.

There is some uncertainty in the variables measured using various instruments. Based on the accuracy of the various instruments, the standards uncertainty is calculated, which shows the possible deviation in measured and calculated parameters. The standard uncertainty is calculated as ([14]; [15])

$$u = \sqrt[3]{a}$$

where 'a' is the accuracy of the instruments and 'u' is the standard uncertainty, which are shown in the below table.

Instruments	Range	Accuracy	uncertainty
Solarimeter	0–1000 W/m2	±1 W/m 2	±0.57 W/m2
Thermocouple -K Type	-50 –110 °C	±1 °C	±0.57 °C
Measuring jar	0–4000 ml	±5 ml	±2.89 ml
Digital TDS meter	0-9990 ppm	±2 %	±1.155 ppm

TABLE NO. II SHOWS ABOUT USED INSTRUMENTS RANGE, ACCURACY AND UNCERTAINTY.

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V. RESULT AND DISCUSSION

The experimental setup is operated in the month of January for five consecutive days from 6 to 10 January for varying water depth in basin (2,4,6,8 and 10 cm). Timing of experiment is from 7:00 am to 7:00 pm. Recording of all variable parameter that is an ambient temperature, glass temperature, vapor and water temperature, basin linear temperature, TDS value and solar radiation are taken hourly.

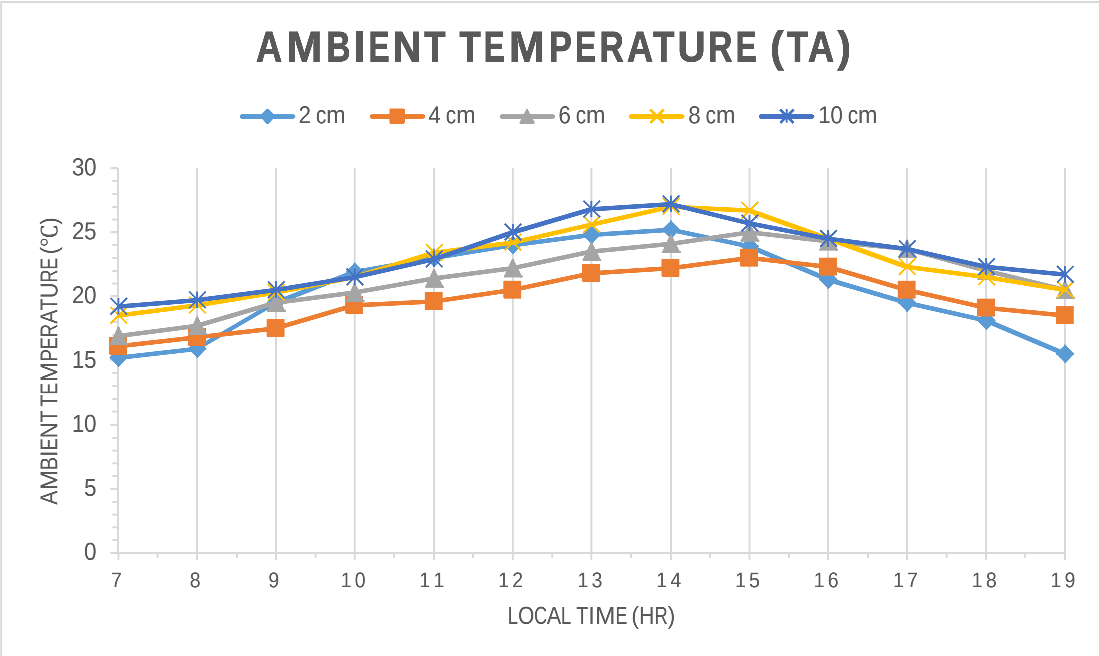

FIG.2 shows the variation of ambient temperature for 12-hour time period with different water basin depths as shown in the figure.

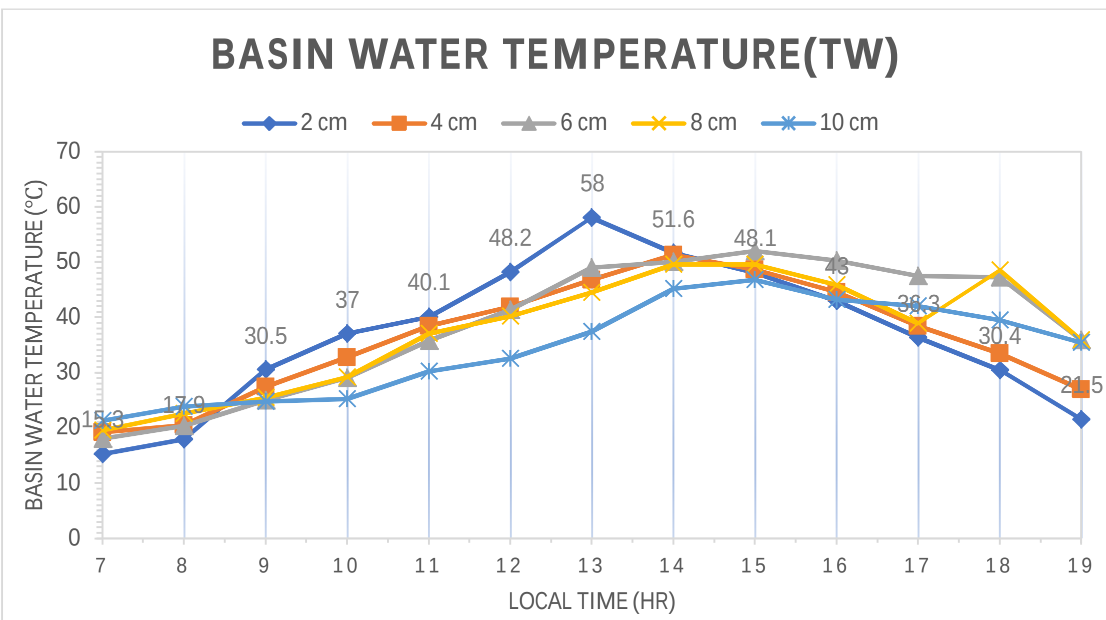

FIG.3 shows the variation of basin water temperature for 12-hour time period with different water basin depths as shown in the figure.

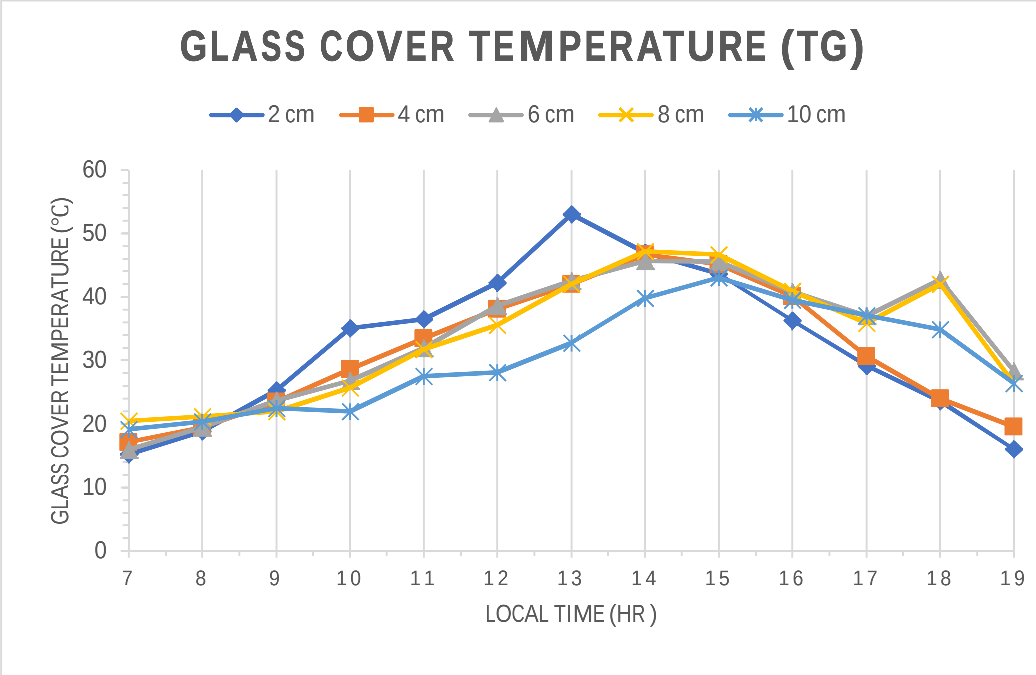

FIG.4 shows the variation of glass cover temperature for 12-hour time period with different water basin depths as shown in the figure.

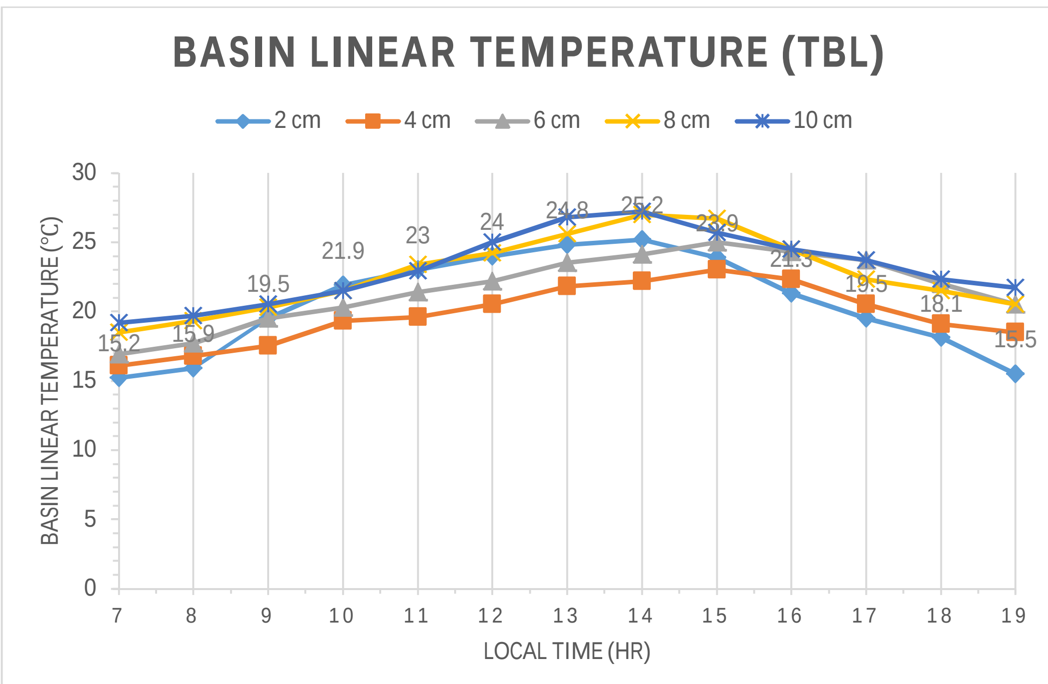

FIG.5 shows the variation of basin linear temperature for 12-hour time period with different water basin depths as shown in the figure.

A. Effect of Basin Water Depth on Productivity

Given figures show the hourly variation of internal heat transfer coefficient (due to convection, radiation and evaporation) from 7:00 to 19:00, for basin water depth from 2cm to 10 cm for pyramid type passive solar still. The maximum value of evaporative heat transfer coefficient reaches between 13:00 and 15:00 for all basin water depth. Where maximum and minimum value of evaporative heat transfer coefficient are 23.1 W/m^2 °C at 2 cm water depth and 7.98W/m^2 °C at 10 cm water depth. It also seen that maximum value of heat transfer coefficient at 2cm is at 13:00 whereas, in case of 10cm basin water depth it is at 15:00. The reason for shifting the maximum value of evaporative heat transfer coefficient is that by increase in basin water depth, the water quantity also increases, that result in increase in thermal inertia of water so, the rate of evaporation decreases as a result, the time of achieving the maximum value of evaporative heat transfer coefficient also shifted from 13:00 to 15:00.

The maximum value of radiative and convective heat transfer coefficient is very less as compare to evaporative heat transfer coefficient. The maximum and minimum value of radiative heat transfer coefficient are 6.6 and 5.4 W/m^2 °C

The maximum and minimum value of convective heat transfer coefficient are 1.9 and 1.38 W/m^2 °C.

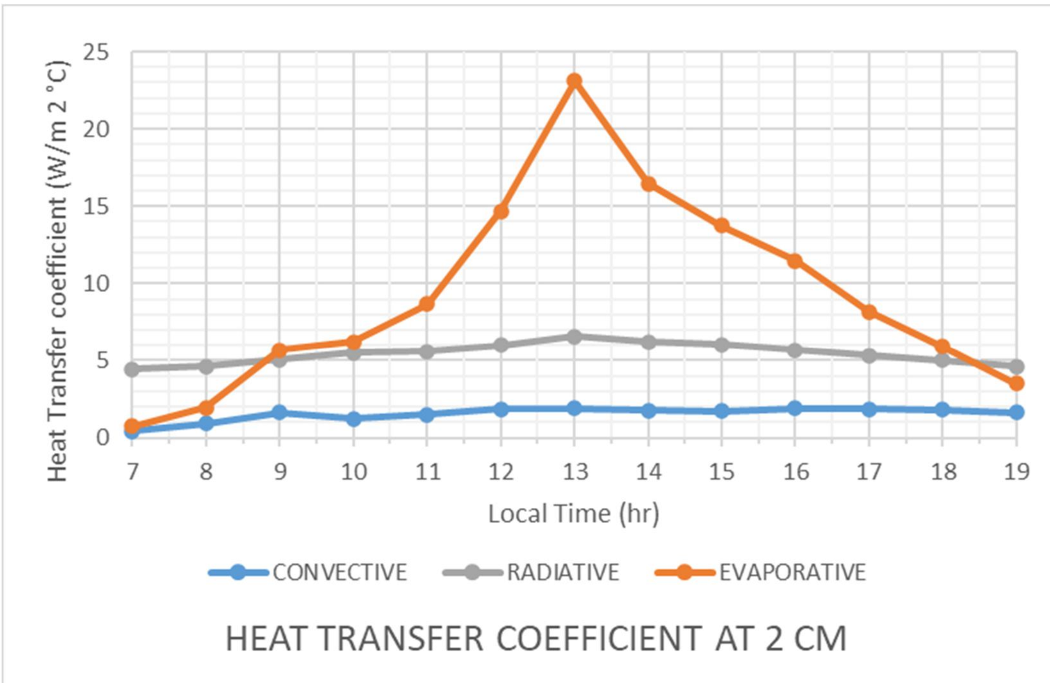

Fig.6 shows variation of heat transfer coefficient with local time at 2cm basin water depth.

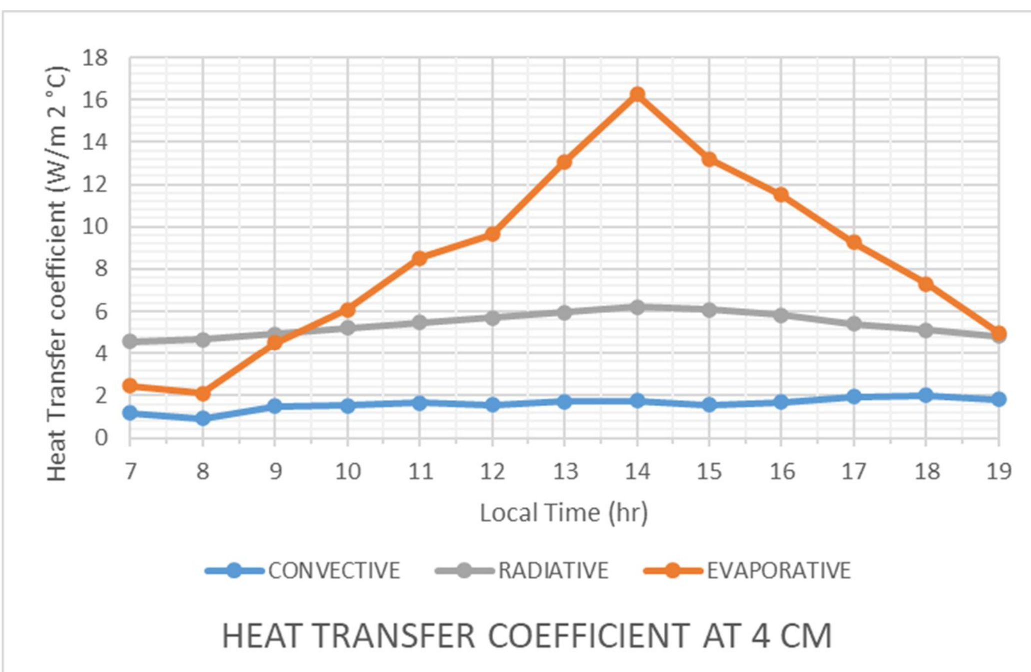

Fig.7 shows variation of heat transfer coefficient with local time at 4cm basin water depth.

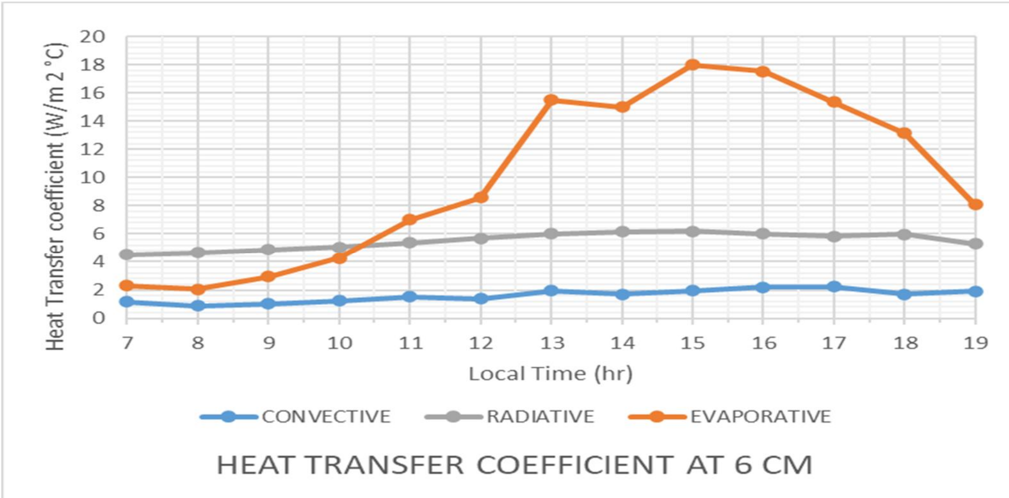

Fig.8 shows variation of heat transfer coefficient with local time at 6cm basin water depth.

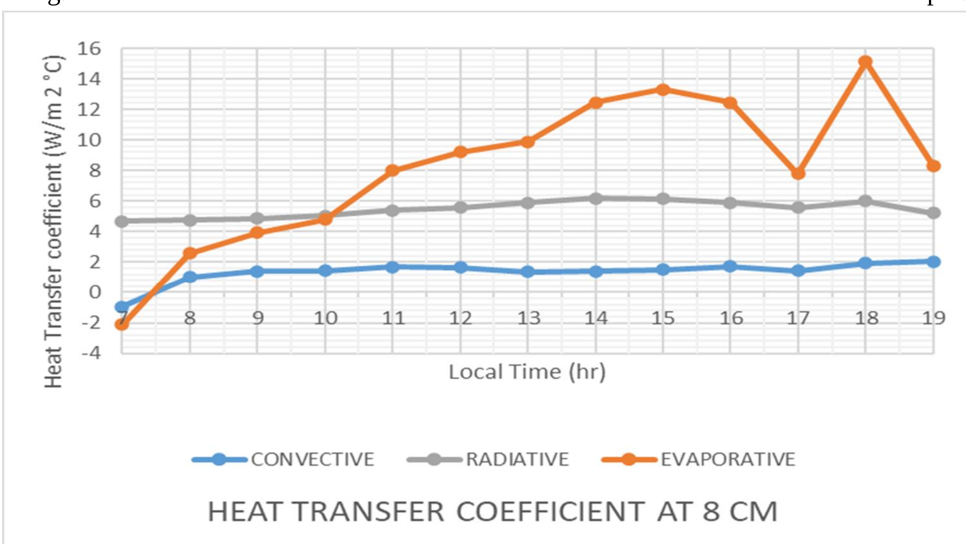

FIG.9 shows variation of heat transfer coefficient with local time at 8cm basin water depth.

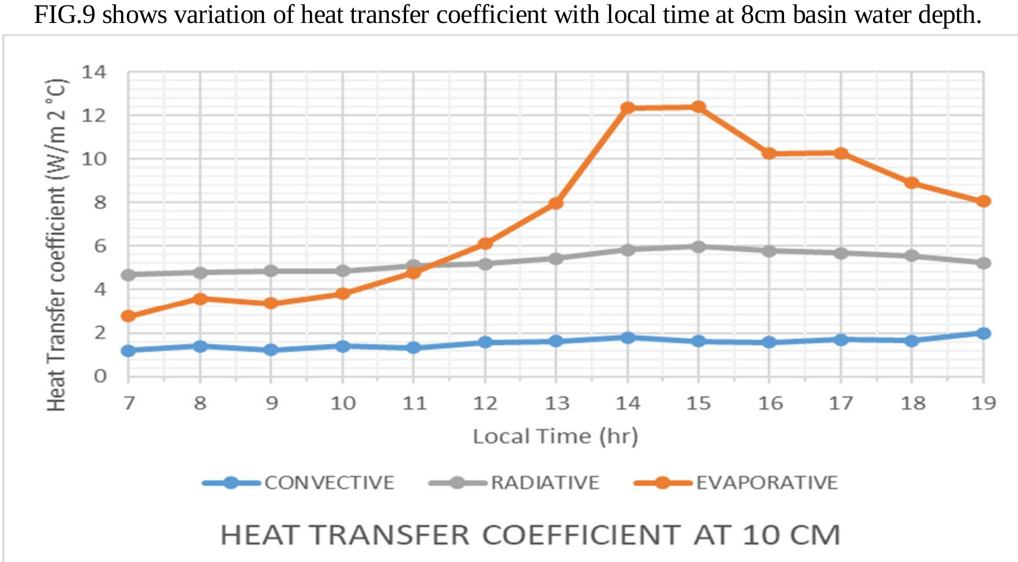

Fig.10 shows variation of heat transfer coefficient with local time at 10cm basin water depth.

Fig.11 shows below hourly variations of distillate for a passive pyramid type solar still. the maximum value of distillate is obtained from 2cm basin water depth and minimum distillate from 10cm depth. So, we can say that distillate is inversely proportional to basin water depth. This is due to higher temperature of low depth basin water that causes high evaporation rate. Therefore, distillate output at 2cm is 513ml/m^2 and for 10cm is 139 ml/m^2. But in case of deeper basin water, distillate output after 15:00 are more consistent as compare to shallower one due to its thermal inertia that causes evaporation.

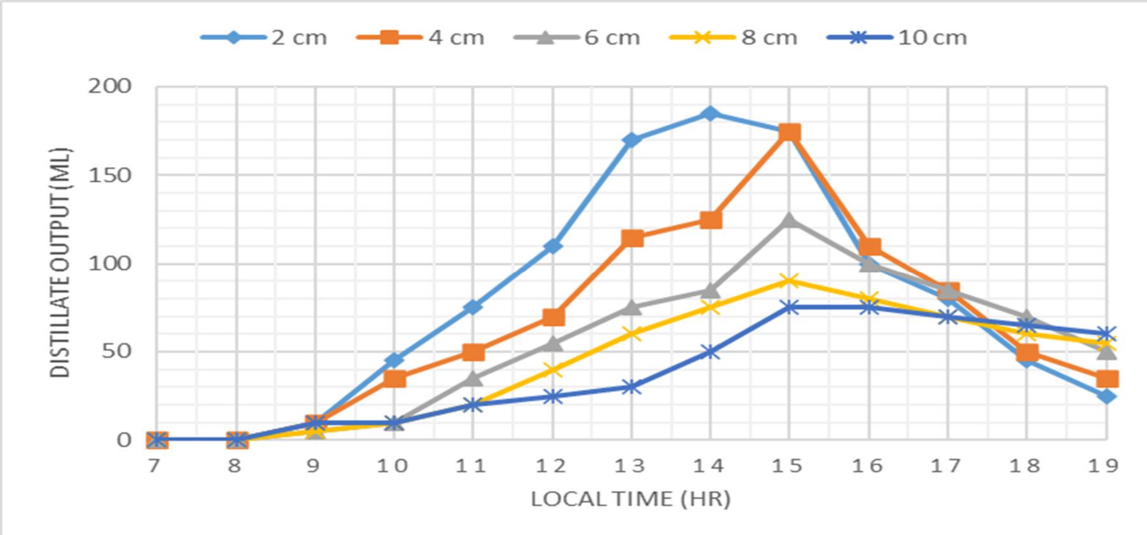

FIG.11 shows hourly variation of distillate output at different basin water depths.

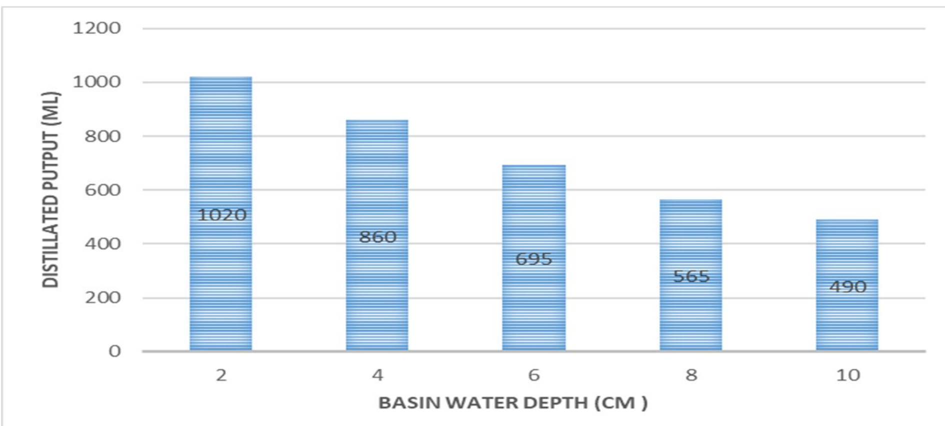

Fig.12 Shows daily distillate output at different basin water depths.

We know that rate of heat loss in evaporation is,

$$q_{ewg} = h_{ewg} \times (T_w - T_g)$$

Also, hourly distillate per unit basin area is,

$$M_w = \frac{h_{ewg} \times (T_w - T_g) \times 3600}{L_{ev}}$$

And, daily distillate output per unit basin area,

$$M'_w = \sum_{n=1}^{12} M_w$$

So, thermal efficiency of solar still is given as,

$$\eta = \frac{M'_w \times L_{ev}}{A_b \times \sum I(t) \times \Delta(t)}$$

Table NO. III Shows Short Comparison Of Productivity Values Obtained By This Experiment And Previous Researcher

S.no	Author	Type of study	Type of solar still	Productivity (Kg/m^2 /day) 2 cm and 10 cm basin water depth	Location /latitude	Season/month of analysis
1. [16]	Nafey et al. (2002)	Experimental	Single basin single slope	3.1 and 2.1	Suez, Egypt/29 .58 ° N	October and November
2.[17]	Tiwari and Maduhri (1987)	Experimental	Single basin single slope with 35° slope angle	2.9 and 2.2	Delhi, India/ 28 .37 ° N	November
3.[18]	Abhay,R.S, and Pankaj (2017)	Experimental	Single basin single slope with 24° angle of slope	4.26 and 3.24	Rewa, India/24 ° 33 N	May
4.[2]	Malik (2018)	Experimental	Pyramid solar still with 30° of slope angle	3.41 kg/m^2 for a water depth of 1 cm to 2.02 kg/m^2 for a depth of 5 cm.	Irbid (jordan)(32.48 ° N and 35.98° E)	September
5.	Present work	Experimental	Pyramid solar still with 23° slope angle	2.83 kg/m^2 for a water depth of 2 cm to 1.4 kg/m^2 for a depth of 10 cm.	Indore (INDIA)	January

Although during literature review mostly the experiment of effect of basin water depth is found in single slope single basin solar still, apart from [2] with 30° slope angle in the month of September. Their maximum and minimum productivity are 3.41 kg/m2 for a water depth of 1 cm and 2.02 kg/m2 for a depth of 5 cm. and our maximum and minimum productivity are 2.83 kg/m2 for a water depth of 2 cm and 1.4 kg/m2 for a depth of 10 cm in the month of January. Difference in the value depends on season and experimental day climatic conditions.

VI. CONCLUSION AND RECOMMENDATIONS

The square base pyramid type passive solar still is fabricated and experimental analysis is done in the central part of India (Indore) with latitude and longitude (22.7196°,75.8577°) in winter season. Reading of number of parameters and results were obtained for different basin water depth ranging from 2cm to 10cm. On the basis of obtained result following conclusion are drawn.

- The maximum value of basin water temperature obtained in 2cm basin water depth is 58°c. whereas in 10cm basin water depth maximum value of basin water temperature is 46.8°c both values are obtained between 13:00 and 15:00.
- The maximum value of evaporative heat transfer coefficient obtained experimentally in 2cm and 10cm are 23.1 W/m^2 °C and 12.4 W/m^2 °C.
- The maximum value of convective heat transfer coefficient obtained experimentally in 2cm and 10cm are 1.9 W/m^2 °C and 1.78 W/m^2 °C.

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- The maximum value of radiative heat transfer coefficient obtained experimentally in 2cm and 10cm are 6.6 W/m^2 °C and 5.97 W/m^2 °C.
- It is observed that the convective and radiative heat transfer coefficient value is very less as compare with evaporative heat transfer coefficient.
- Maximum heat transfer coefficient values are mostly obtained between 13:00 and 15:00.
- The maximum distillate output obtained in 2cm water basin depth is 185ml at 14:00. and maximum distillate output obtained in 10cm water basin depth is 75ml at 15:00-16:00.
- The distillate output obtained at 2cm and 10cm basin water depth are 2.83 kg/m^2 and 1.4 kg/m^2. So, distillate output become half when increasing the basin water depth by a factor of 5.

So, it can be concluded that the effect of basin water depth in the productivity of pyramid type passive solar is in inversely proportional. Which is clearly seen in the result than by increasing the basin water depth from 2cm to 10cm decrease output distillate from 2.83 kg/m^2 to 1.4 kg/m^2. The value of convective and radiative heat transfer coefficient is very less as compare to evaporative heat transfer coefficient. Maximum distillate output, heat transfer coefficient value are obtained in between 13:00 and 15:00 due to high incoming solar irradiance.

A. Recommendation for Future Work

Due to solar still economical, ecofriendly and easy to operating advantage it is great to work in this domain for more effective distillation. For that we can investigate the interaction between basin water depth and additional operating parameters such as varying insulation material, nano fluids, humidity, wind speed and heat absorber materials.

Also, we can done long term performance studies to assess the impact of salt accumulation, scaling, and material degradation on productivity at different water depths.

We can also conduct the above experiment with additional source of energy that is, in Active pyramid solar still. Also, comparative studies between different geometrical shapes can also be done. We can also assess eco-friendly materials for basin construction, for its recycling or biodegradable use.

These directions are aim to bridge gaps in practical implementation, enhance adaptability across regions and promote solar still as a sustainable water purification system.

VII. APPENDIX

The Following formula and data have been used for solving numerical calculations.

The formulas of partial vapor with the function of temperature are as follows [19]

$$P_{w=}\left\{25.317-\frac{5144}{(T_w+273)}\right\}$$
$$P_{g=}\left\{25.317-\frac{5144}{(T_g+273)}\right\}$$

The latent heat of evaporation of water is calculated by the given expression.[20]

$$L_{ev} = (2501.67 - 2.389 \times T_w) \times 10^3\ J/kg$$
$$\varepsilon_{eff} = \frac{1}{\left(\frac{1}{\varepsilon_w}+\frac{1}{\varepsilon_g}+1\right)}$$

Emissivity values are taken by[21]

$$\varepsilon_w = 0.95$$
$$\varepsilon_g = 0.94$$
$$\varepsilon_{eff} = 0.82$$

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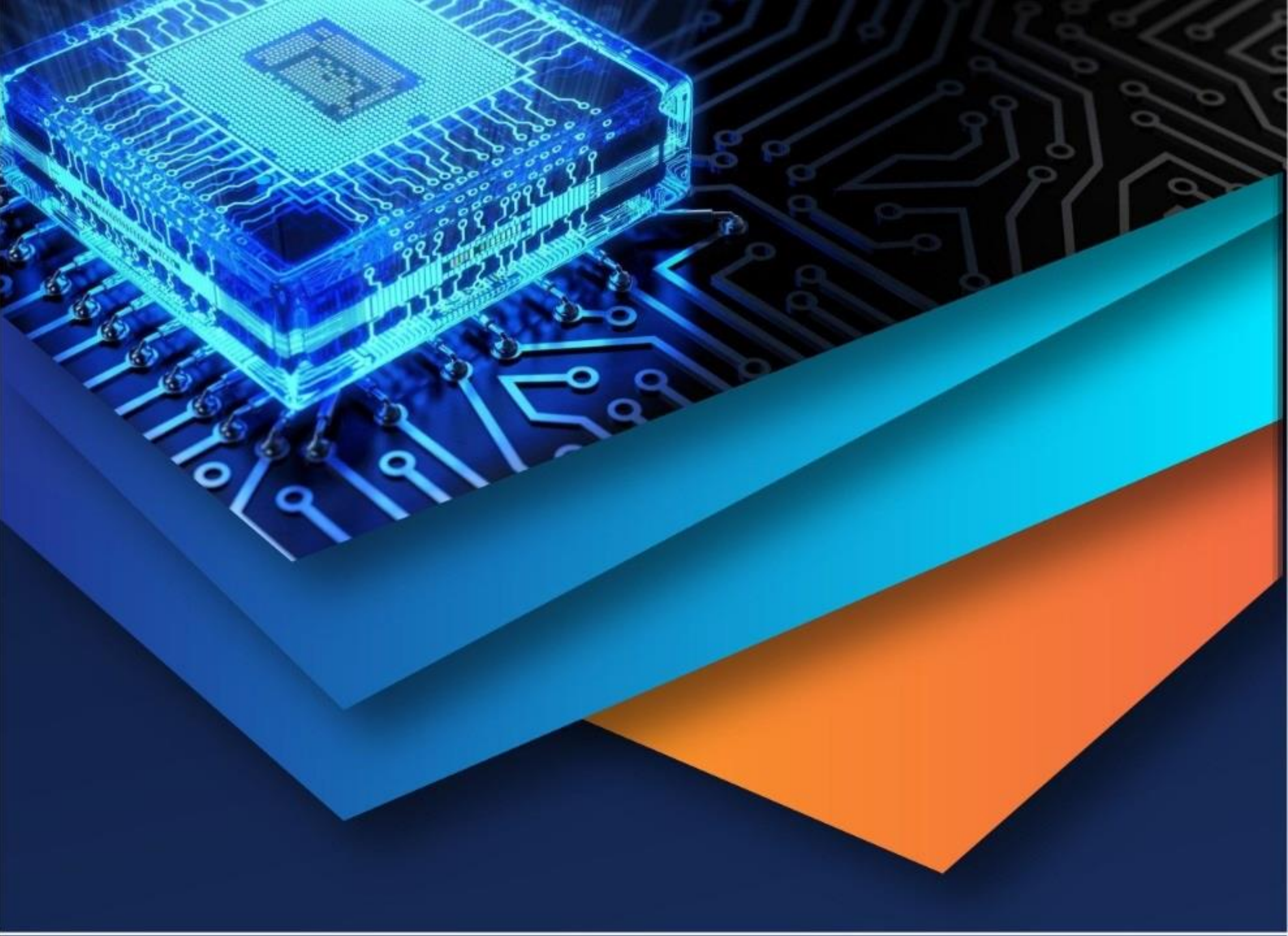

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