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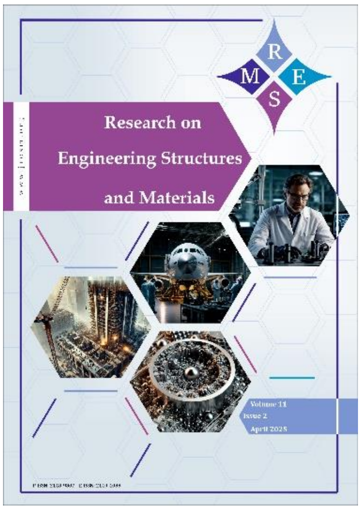

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Research Article

Performance enhancement of solar still using Al_2O_3–CuO hybrid nanofluid: A comparative study at varying basin water depths

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Abstract

Water scarcity remains a pressing global concern, particularly in dry and semi-dry areas where it is difficult to obtain water that is safe to drink. This experimental study focuses on enhancing the total yield and efficacy of solar still that uses Al_2O_3–CuO (50:50 ratios) based hybrid nano fluid stored in silver (Ag) cylinder. In this study the impact of basin water depth on total distillate is carried out by comparative analysis of conventional, nano fluid and hybrid nano fluid based solar stills. The experimental values of hybrid nano fluid indicate maximum distillate of 689 ml whereas 605 ml for CuO, 570 ml for Al_2O_3 and 530 ml for conventional solar still. This illustrates that hybrid nano fluid improves distillate. The performance enhancement of solar still is carried out by using hybrid nano fluid in the context of maximum distillate at basin water depths of 2 cm, 3 cm and 4 cm respectively. The result shows maximum yield 689 ml is obtained at 2 cm water depth for Al_2O_3 – CuO hybrid nano fluid based solar still at 0.1% concentration which is higher than others such as 598 ml and 488 ml received for 3 cm and 4 cm water depth respectively. Also, thermal energy balance equations and coefficient of heat transfer have been studied for 2 cm, 3 cm and 4 cm water depths. The highest amount of evaporative heat transfer coefficients (hewg) is 32.23 W/m2 K at 2 cm while 23.06 W/m2 K at 3 cm and 12.90 W/m2 K at 4 cm water depth respectively. Due to this reason, high rate of evaporation of basin water takes place and total yield is enhanced at 2 cm water depth. This analysis depicts that Al2O3 – CuO hybrid nano fluid performs more favorable than nano fluid and conventional solar still.

1. Introduction

One of the fundamental and necessary components of this planet is water. Its unique properties make it essential for sustaining all forms of life and supporting a multitude of natural processes. Water is not just a chemical compound; it is the foundation of existence itself. Its importance spans across numerous domains, from ecological balance to human health, agriculture, industry, and beyond. Without water, life would not exist as we know it.

For the general public's health, sanitation, and well-being, access to clean, safe drinking water is crucial. Contaminated water can harbor pathogens and toxins that cause waterborne diseases, causes of illness, morbidity, as well as death, especially in sensitive groups such as older people and children [1]. Thus, it is necessary to create an affordable technique which easily purifies the contaminated water. Solar distillation offers a sustainable and cost-effective method for water

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purification, producing potable water by utilizing solar energy. That is predicted on the concepts of condensation and evaporation of water purification. But in comparison to other distillation processes, it is incredibly inefficient and productive. Hence, it is vital to improve the design parameters as well as operational protocols of solar stills for augmenting their efficiency and output. There are so many studies are made regarding design improvement and modifications like basin water depth and nano fluid concentrations. The operational parameters, like basin water 's depth, were examined in the various solar still designs for increasing production and working conditions [2]. For the same water quantity and water depth, a comparison is made between the traditional still and the finned and corrugated still. According to the results, the overall performance of solar stills with fins as well as corrugations was roughly 40% and 21% greater, respectively, compared to traditional stills [3].

The daily production of the potable water from solar still reduced as the basin water's depth grew. Around 41.49% of the reported daily efficiency was noted for identical depth in basin water, the predicted daily efficiency value was roughly 52.83% as well as 41.75% for different depth of basin water such as 2 cm and 10 cm [4]. To achieve experimentally effectiveness of still, three different types of phase change materials were filled into the copper metal cylinder at different basin water depth 1-5 cm. The results were observed that when the water depth rises from 1 to 5 cm in comparison to lauric acid (21.5%) as well as stearic acid (17.6%), it is observed that a 9.2% reduction in paraffin wax's maximum temperature of basin water [5]. The performance of still is poor; its efficiency is about 30%. It has been noted that thermal efficiency drops as water depth and salinity rise. The main factor that increases yield is the evaporative heat component, which decreases as basin water salinity and depth grow [6].

The study uses an Al_2O_3-CuO hybrid nanofluid at 0.025% concentration to construct still model. The hybrid nanofluid increases still's productivity throughout day around 27.2% as well as output yield by 21.7% compared to still without nanofluid. Since summer time still's efficiency is further enhanced by 49.54% as well as 23.212% in winter. It also enhances energy efficiency by 13.4% in winter and 22.5% in summer [7]. CuO, Al_2O_3, Ag, SiC and Fe_2O_3 water based nanofluids were added to solar still attached with single slope (passive type) at varying volume concentrations (0.02, 0.05, 0.12, and 0.2). The optimal water depth for this examination was determined to be 0.02 meters. The total distillate output from a still, both theoretical and experimental, was found to be 12.24%. It was discovered that Al_2O_3-water-based nanofluid had daily productivity of 14.22% larger than that of traditional still. Similarly, CuO (10.82%), Ag (8.11%), SiC (7.61%) and Fe_2O_3 (7.63%) water based nanofluids were the next highest producing volumes of potable water daily [8]. A solar still with five different brine depths 1, 4, 6, 8, and 10 cm was constructed and tested, in order to do an experimental inquiry aimed at verifying this tendency. The current study shown that the brine depth could have an up to 48% impact on still productivity and confirmed the trend of declining productivity with increasing brine depth [9].

Hybrid nanofluids were employed in conventional solar stills to maximize their performance. When Al_2O_3-SiO_2 water-based hybrid nanofluid were used total yield, thermal as well as exergy efficiency of still were improved by 4.99 kg/m^2 per day, 37.76%, and 0.82%, respectively. Along with solar insolation, ambient temperature, flow rate of nanofluid, concentration of nanoparticles, inlet heat exchanger temperature, and basin water depth all played crucial roles in enhancing performance [10]. An investigation was carried out to demonstrate the impact of adding copper oxide (CuO) nanoparticles at various water depths in a typical still. Such modified still's water productivity was found to be 3445 mL/m^2 at a depth of 5 cm as well as 3058 mL/m^2 at a water depth of 10 cm per day [11]. A modification was carried out on the conventional solar still to demonstrate the consequences of different nanoparticle applications on the thermal efficiency of traditional still. According to the findings, using cuprous oxide (Cu_2O) as well as aluminum oxide (Al_2O_3) nanoparticles during daylight accelerated the rate of water productivity [12]. A study showed the effectiveness of water based CuO-SiO_2 hybrid nano fluid on heat transfer enhancement in turbulent condition through the horizontal tube is numerically computed by using a CFD program. The result indicated that CuO has greater thermal conductivity than SiO_2, and due to this increased convective heat transfer coefficient obtained [13]. Use of Aluminum oxide (Al_2O_3) nano particle in refrigerant enhances thermal conductivity of M/Alumina nano refrigerant is 18.1% more than that of

R410a/Alumina. Also Heat extraction is augmented from the evaporator by adding Aluminum oxide (Al_2O_3) nanoparticles to the refrigerants [14]. The study analyzed titania (TiO_2) and carbon nanotubes (CNTs) for creating TiO_2/CNTs nano composites which have the potential to be hybrid nano fillers in nano fluids for machining carbon fiber reinforced plastics (CFRPs). The result depicts, titania (TiO2) nano composites and carbon nano tubes (CNT) may be reliable filler choices for blending hybrid nano fluids for machining operations [15].

Using of hybrid nano particles in solar distillation process gives enhanced performance relative to single nanoparticles. The mixture of Aluminum oxide and copper oxide and particles enhances thermal conductivity heat retention solar absorption and anti-microbial properties. These hybrid nanoparticles act synergistically to boost water evaporation rates augment freshwater yield and prevent fouling in solar distillation systems. As compared to using them individually the mixture of hybrid nanofluid Al_2O_3 (30 W/m·K) and CuO (33 W/m·K) gives a nanofluid with greater thermal conductivity. Higher evaporation rates and fast heating are the consequences of hybrid nanofluids enhanced heat transmission from the solar absorber to the water due to this better thermal stability and less energy losses in distillation process that make it possible by synergistic effect. Due to high specific heat capacity of Al_2O_3 (0.775 J/g·K) and CuO (0.53 J/g·K) hybrid nanofluid gives better heat storage and distribution. This assures continuous evaporation even in varying solar conditions [16]. The hybrid nanoparticle mixture enhances photon trapping, enhancing heat absorption within the solar still. This heats up the water and boosts evaporation rates since CuO has black color which causes strong solar absorption capacity, while Al_2O_3 causes efficient distribution of this absorbed heat. The hybrid combination reduces energy loss by assuring various lights scattering inside the solar still. Al_2O_3 contributes to reflect excess heat, avoiding overheating and maintaining effective thermal balance. Al_2O_3-CuO hybrid nanofluids can raise total yield by 40 to 60%. Improves solar distillation efficiency by reducing energy use and works effectively even in low sunlight.

The literature review mentioned above demonstrates that the use of different nano fluids in different variables like (basin water depth, concentration of nano materials etc.) enhance the effectiveness of still due to enhancing high heat transfer carriers of nano materials. In that scenario, nano fluid is crucial to enhance still's overall effectiveness in the form of efficiency and exergy as well as enhanced total distillate compared to conventional type solar still. There are limited literatures are available related to hybrid nano fluid of Al_2O_3 – CuO based (at 50:50 ratio) which works in Indian atmospheric conditions at different parameters like concentrations of hybrid nano fluid and depth of basin water. Consequently, an attempt has been made in the current work to use hybrid nano fluid with varying concentrations of nano materials in order to enhance solar stills' performance.

2. Experimental Setup and Procedures

The experimental work is carriedout at Mechanical Engineering Department, Madan Mohan Malaviya University of Technology, Gorakhpur Uttar Pradesh, India (Latitude 26.7304, Longitude 84.4325) and readings were recorded at every half an hour in the month of June 05, 2023.

Table 1. Technical specification of experimental setup

Parameters	Dimensions
Solar Still (Length × Breadth)	50cm x 50cm
Solar Still (Lower Height × Higher Height)	15cm x 52.7cm
External Reflector ($l_2 \times b_2 \times t_2$)	50cm ×50cm × 03mm
External Reflector Angle from Highest Height	Choosing maximum distillate output at particular angle 20^0
Internal Reflector ($l_3 \times b_3 \times t_3$)	50cm ×15cm × 03mm
Glass Sheet ($l_4 \times b_4 \times t_4$)	50cm ×65cm × 03mm
Aluminum Sheet ($l_5 \times b_5 \times t_5$)	50cm ×50cm × 16 gauge

Solar irradiation, wind velocity and ambient temperature are taken at MMMUT Gorakhpur, Uttar Pradesh, India. The schematic design of still is displayed in Fig. 1. It is made up of wooden plywood block. It consists of mainly solar basin; single glass covers as well as solar collector. The front side of basin is south facing. Its basin size is 50x50 cm^2, basin surface is attached with aluminum plate and black painted to enhance adsorption of the solar irradiation, while, it's height from front and back are 12 cm and 60 cm respectively shown in Fig. 2. Solar still is attached with external reflector with size of 50x50 cm^2, inner side walls of basin is fixed with internal reflector. A comprehensive overview of all the experimental setup details mentions in Table 1.

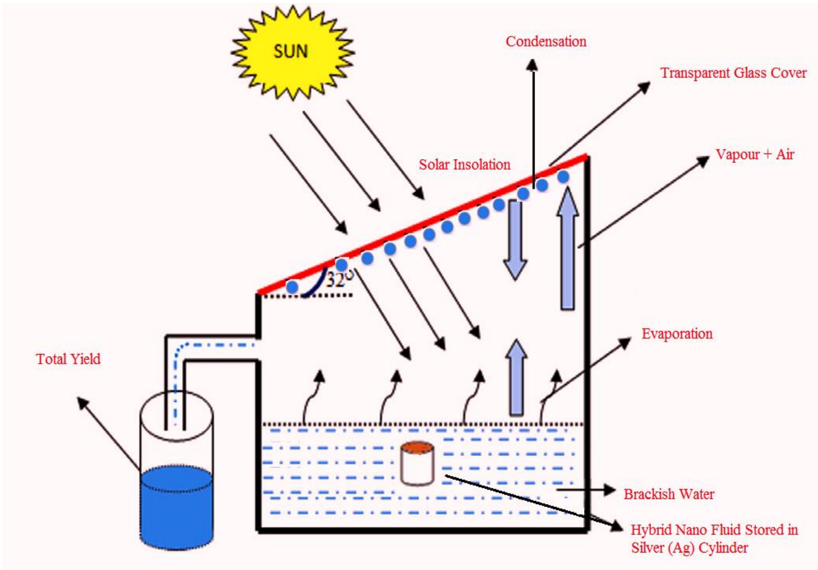

Fig. 1. Diagrammatic design of still with hybrid nano in Ag cylinder

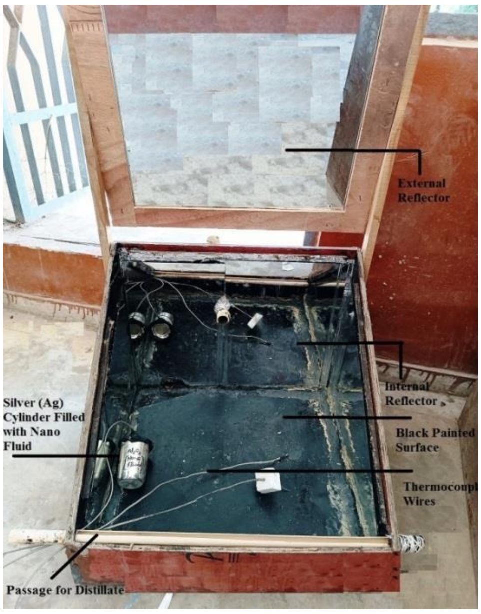

Fig. 2. Experimental setup of still

2.1 Fundamentals of Operation

It can be illustrated through Fig. 1, wherein solar irradiation passes over the glass cover and is taken up by basin liner as well as silver (Ag) cylinder, raising the temperature. This single silver (Ag) cylinder (190 ml size) is filled with hybrid nano fluid. A portion of the irradiation (measured by Pyranometer "Kipp & Zonen CMP10 Class A") that the liner in the basin absorbs, which is shown in Fig. 1, is transferred to water in the basin by convection. Temperature of silver (Ag) cylinder continuously increases by solar irradiation as well as convective heat transfer from water. At this time, hybrid nano fluid heats up and achieves high temperature (measured by Digital thermo-hygrometer "Model: Fluke") at 12:00 PM. Resulting enhances the basin water temperature. Due to this high amount of heat that is transfer from Ag cylinder to water in the basin, increased evaporation of water in the basin takes place. After that when this evaporated vapour are reached at glass cover, condensation takes place and this condensate converts into droplets, that is stored in jar as a potable water as total distillate.

When two distinct nanoparticles such as Al_2O_3 and CuO are added in a base fluid, each adds unique thermo physical characteristics. Metal oxide nanoparticles (Al_2O_3) enhance stability and specific heat capacity, whereas metallic nanoparticles (CuO) increase thermal conductivity. Together, their combined effect forms a fluid with balanced and enhanced heat transfer characteristics. Due to the different heat conduction paths created by heterogeneous particles, hybrid nanofluids have a higher effective thermal conductivity than single-type nanofluid. The Brownian motion of nanoparticles with various sizes and densities enhances micro-convection in the fluid, further increasing thermal transport. This improved heat transfer accelerates basin water temperature rise, leading to higher evaporation rates. Higher evaporation increases the temperature gradient between the evaporating surface and condensing cover, enhancing condensation and thereby raising total yield.

2.2. Formation of Al_2O_3 – CuO Based (at 50:50 Ratios) Hybrid Nano Fluid

The formation of a Hybrid nanofluid involves the dispersion of nanometer-sized particles (nanoparticles) of Al_2O_3 and CuO at ratio of 50:50 into a base fluid water to create a stable mixture of different concentrations. It is completely based on its applications which will become right mixing of nanoparticles as Al_2O_3 and CuO (shown in Fig. 4) with base fluid water.

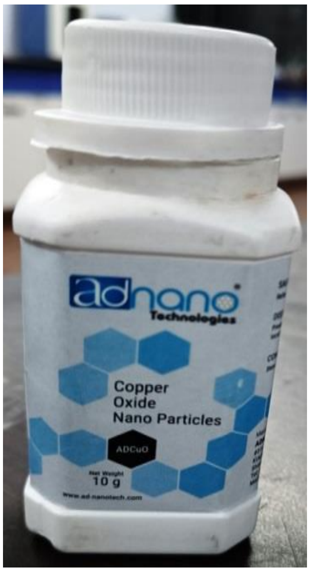

Fig. 3. CuO Nano Particle

Fig. 4. Al_2O_3 – CuO based (at 50:50 ratio) hybrid nano fluid formation by two step method

For preparation of nano fluid, nanoparticles of Al_2O_3 and CuO (shown in Fig. 3) are selected. Then, weigh these two nanoparticles Al_2O_3 and CuO, using the digital scale to measure concentration of 0.1%. For making 0.1% concentration for hybrid nano fluid, weighing equal quantity (at 50:50 ratio) of Al_2O_3 and CuO and put into a beaker with base fluid of water at 190 ml quantity. Then mixture is stirred by magnetic stirrer at 1000 RPM for 45 minutes. After that this mixture is placed into the ultrasonicator at 318 K – 320 K for 2 hours shown in Fig. 4. Thus, solution of hybrid nano fluid at 0.1% is formed which is stored into the silver (Ag) cylinder for experiment as shown in Fig. 5. This hybrid nanofluid may be a useful solar-powered method of desalinating water.

Fig. 5. Al_2O_3 – CuO based hybrid nano fluid Stored in Ag Cylinder

3. Thermal Energy Computations for the Solar Still Model

Based on the energy balance equations for each of its three components (saline water, absorber plate as well as transparent glass cover), the thermal model of still is presented in Figure 1. Each component of still has energy balance equation that is derived from its average temperature. Considering the presumptions mentioned [17],

- In comparison to the basin water, the heat carrying capability of the insulating materials (from bottom as well as sides) and condensing cover is insignificant.
- It is considered that a solar still is an ideal vapor leakage proof device.
- It is presumed that dry air and water vapor act as perfect gases.
- Different temperature ranges do not affect the physical characteristics of the water used in the experiment.

In essence, thermal modeling for solar stills consists of a set of mathematical formulas for energy transmission at different still locations. Thermal modeling allows for the efficient evaluation of the design of systems for solar distillation for a wide range of parameters. The equations based on energy balance are described as;

$$\alpha'_g I(t) + Q_{twg} = Q_{tga} \tag{1}$$

$$Q_{twg} = Q_{cwg} + Q_{ewg} + Q_{rwg} \tag{2}$$

$$Q_{tga} = Q_{cga} + Q_{rga} \tag{3}$$

$$\alpha'_g I(t) + h_{twg} (T_w - T_g) = h_{tga} (T_g - T_a) \tag{4}$$

The energy balance equations listed below are prepared for thermal modeling of the several components of still, including the basin liner, glass cover as well as water mass [18].

3.1 Glass Cover

Since heat is absorbed by the glass cover from incident irradiation and rejected by the glass cover to the atmosphere through convection and radiation as a portion of total sun radiation as well as water surface in basin (convection, evaporation, and radiation).

3.2 Basin Water

A portion of transmitted solar radiation falls in to the water in basin, which absorbs thermal energy and transfers it to the basin liner's water. Heat energy that has been absorbed is used in two ways: first, it is trapped in to water because of specific heat of water; second, it is moved from the water surface to the glass cover by radiation, evaporation as well as convection.

$$\alpha'_w I(t) + Q_{cbw} = Q_{twg} + m_w c_w (dT_w/dt) \quad (5)$$

$$\alpha'_w I(t) + h_{cbw} (T_b - T_w) = h_{twg} (Tw - T_g) + m_w c_w (dT_w/dt) \quad (6)$$

3.3 Basin Lining

Since fraction of transmitted irradiation that strikes basin liner, thermal energy is collected by the liner and released into water in basin. By conduction and convection through the still's bottom as well as sides, the residual heat is released from the liner in basin to the atmosphere.

$$\alpha'_b I(t) = Q_{cbw} + Q_{tba} \quad (7)$$

$$\alpha'_b I(t) = h_{cbw} (T_b - T_w) + h_{tba} (T_b - T_a) \quad (8)$$

3.4 An Analogy of Heat Transfer in Solar Still

The heat transfer process is regulated by three methods: radiation, evaporation, as well as convection in a distillation unit. Heat transfer occurs from water in basin to the inner surface of the glass cover. Convective heat transmission occurs between inner side of glass cover and basin's water surface. The following equation is used to compute it:

$$Q_{cwg} = h_{cwg} \times (T_w - T_{gi}) \quad (9)$$

Here h_{cwg} (W/m^2 K) is the convective heat transfer coefficient from basin water to the inner side of glass cover and examined by Equation (10) as shown in (Dunkle 1961) relations [19].

$$hcwg = 0.884 \left[(Tw - Tgi) + \left\{\frac{(Pw-Pgi)(Tw+273.15)}{(268900-Pw)}\right\}\right] ⅓ \quad (10)$$

Here Pw (N/m2) & Pgi (N/m2) can be examined by Equations. (11) & (12) relations [18, 19]

$$Pw = exp\left\{25.317 - \frac{5144}{Tw + 273}\right\} \quad (11)$$

$$Pgi = exp\left\{25.317 - \frac{5144}{Tgi + 273}\right\} \quad (12)$$

The evaporative heat transfer takes place between the water surface as well as glass cover in the form of the water to the air-vapor mixture (humid air). Rate of evaporative heat transfer is written as in equation (13):

$$Q_{ewg} = h_{ewg} \times (T_w - T_{gi}) \quad (13)$$

Here, hewg is evaporative heat transfer coefficient from the glass cover inner side to the water in the basin which is examined by equation (14):

$$hewg = 13.273 \times 10^{-3} \times hcwg \left[\frac{Pw - Pgi}{Tw - Tgi}\right] \quad (14)$$

The radiative heat transfer rate from inner side glass covers as well as basin water is examined by equation (15), [20, 21];

$$Q_{rwg} = h_{rwg} \times (T_w - T_{gi}) \quad (15)$$

The radiative heat transfer is also written as Stefan Boltzman's equation;

$$Qrwg = \varepsilon eff\sigma[(Tw + 273)^4 - (Tgi + 273)^4] \quad (16)$$

where ε_{eff} *is* the water surface's effective emissivity towards glass cover as well as σ denotes Stefan Boltzman's constant which is equal to 5.67 ×10 −8 W/m^2 K^4, hrwg (W/m^2 K). The radiative heat transfer coefficient is examined by equation (17);

$$hrwg = \frac{\varepsilon eff\sigma[(Tw + 273)^4 - (Tgi + 273)^4]}{(Tw - Tgi)} \quad (17)$$

And the effective remittance is written as in equation (18);

$$\varepsilon e = \{\left(\frac{1}{\varepsilon w}⅓\right) + \left(\frac{1}{\varepsilon g}\right) - 1\} \quad (18)$$

Total heat transfer rate (Qtwg) as shown in equation (19) & (20);

$$Q_{twg} = Q_{cwg} + Q_{rwg} + Q_{ewg} \quad (19)$$

$$Q_{twg} = h_{twg} \times (T_w - T_{gi}) \quad (20)$$

The coefficient of total internal heat transfer (h_{twg}) is written as in equation (21):

$$h_{twg} = h_{cwg} + h_{rwg} + h_{ewg} \quad (21)$$

where, T_{gi}, T_w, as well as T_a are the glass cover innerside, water and atmospheric temperature in K.

4. Results and Discussions

4.1. Variation Of Solar Intensity and Atmospheric Temperature for Different Basin Water Depths 2cm, 3cm and 4cm

Fig. 6 shows variation of solar intensity every hour, atmospheric temperature with time throughout day at 2cm, 3cm & 4cm basin water depth. The experiment is conducted continue three days on June 05, 06 & 07, 2023 and for three distinct water depths in the basin, average values have been provided.

The trend shows that solar intensity increases from 9 AM to 12 AM, after that it starts decreasing from 12 AM to 5 PM and when sunset occurred, solar insolation will be zero. The maximum solar intensity and ambient temperature Ta are 1001 W/m^2 and 323 K at 12PM at 4 cm basin water depth on June 07, 2023. While 998 W/m^2 and 321 K at 2 cm water depth as well as 996 W/m^2 and 322 K at 3 cm water depth at 12 PM on June 05, 2023 and June 06, 2023 respectively.

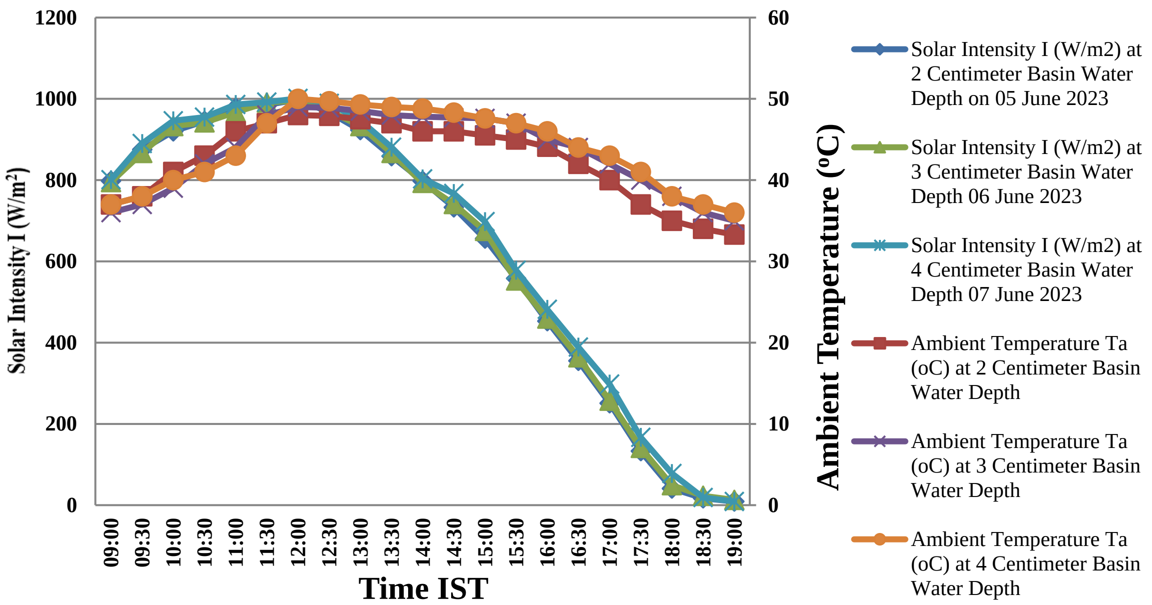

Fig. 6. Graphical representation of solar insolation, ambient temperature with time at 2cm, 3cm and 4cm basin water depth

4.2. Variation of Temperature of The Glass Cover (TGI) For Distinct Basin Water Depths 2cm, 3cm and 4cm

From Fig. 7 it is illustrated that temperature of the glass cover enhances continuously up to 12:00 PM and maximum temperature 322 K at 2 cm water depth is attained but after that it decreases simultaneously whereas for 3 cm basin water depth, glass cover temperature attains 317 K and for 4 cm water depth, 319 K glass cover temperature is achieved. Since it is often seen that at early morning the glass cover temperature is approximately equal to basin water temperature (Tw) but as the day continuously in progress, this variation of temperature of water into basin as well as glass cover increases. This is carried out because the basin temperature absorbs incident solar radiation and glass cover plate mostly transmits incident solar insolation.

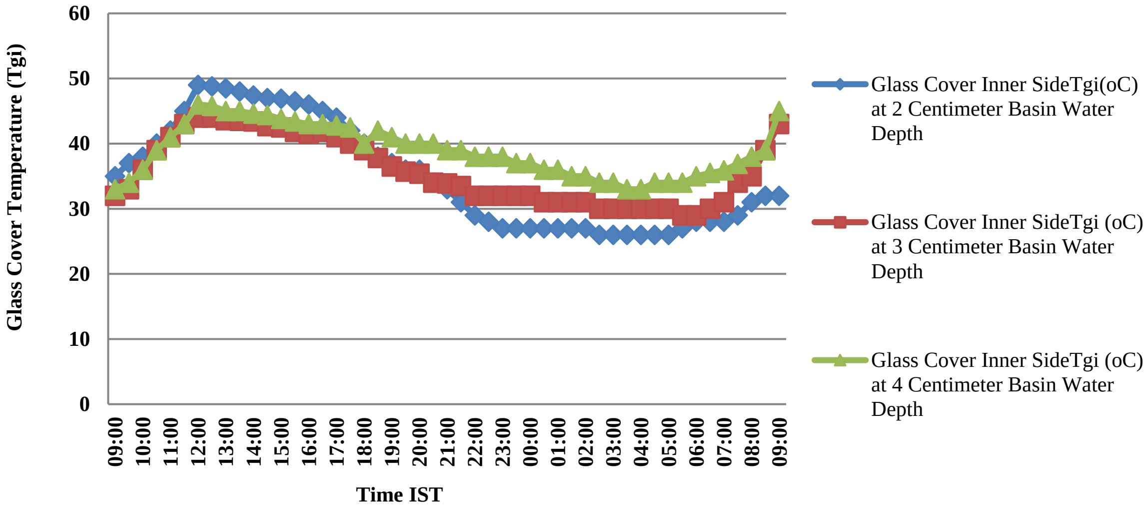

Fig. 7. Experimental Values of glass covers temperature with time at 2cm, 3cm & 4cm basin water depth

4.3. Water Temperature Variation in The Basin (Tw) At Various Water Depths

Here Fig. 8, Fig. 9 and Fig. 10 indicate comparative analysis of water temperatures (Tw) inside basin with respect to time at water depths 2 cm, 3 cm and 4 cm for conventional and different nano fluids such as Al_2O_3, CuO and Hybrid Nano fluid (Al_2O_3 & CuO of 50:50 at 1% concentration) based solar stills.

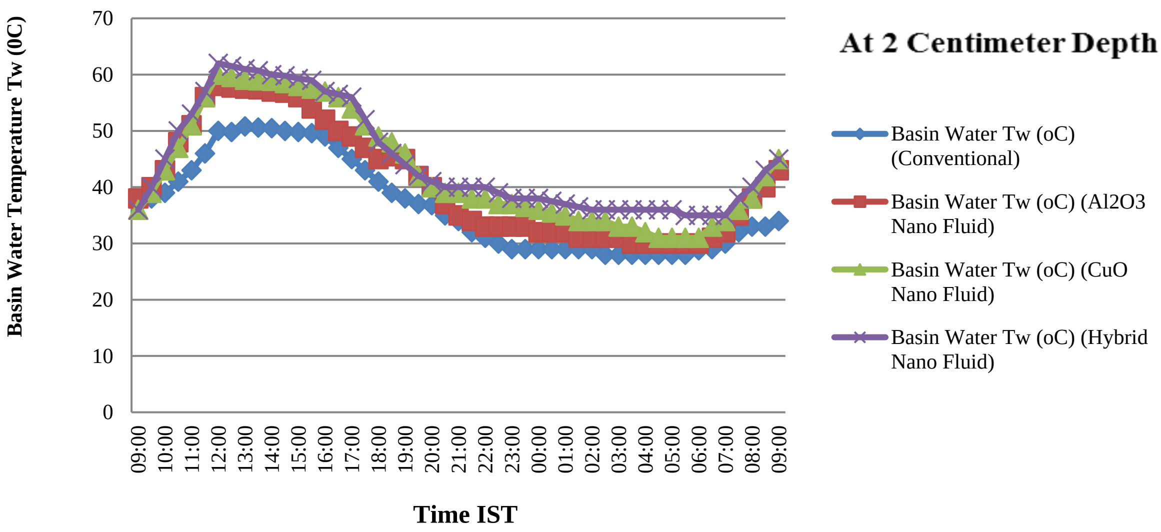

Fig. 8. Basin water temperature (Tw) at 2 cm water depth

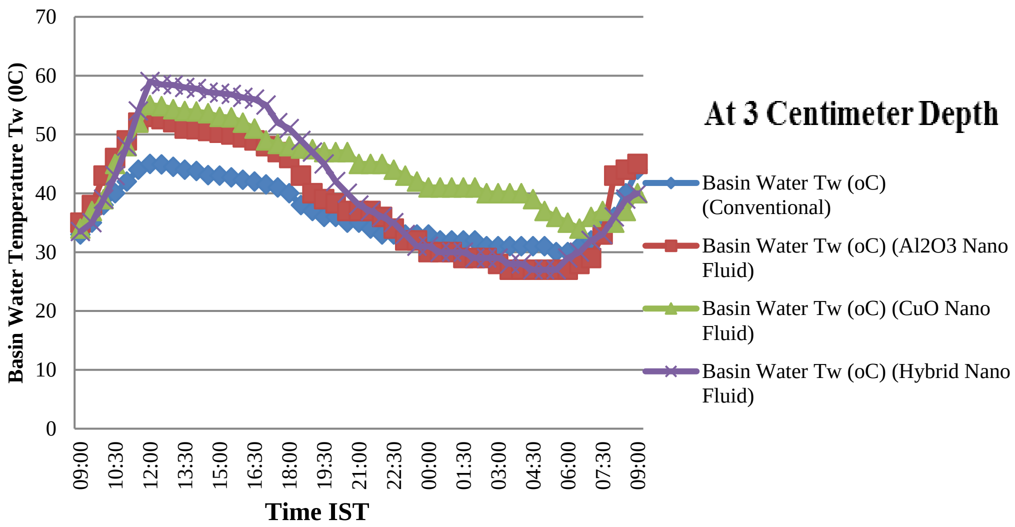

Fig. 9. Basin water temperature (Tw) at 3 cm water depth

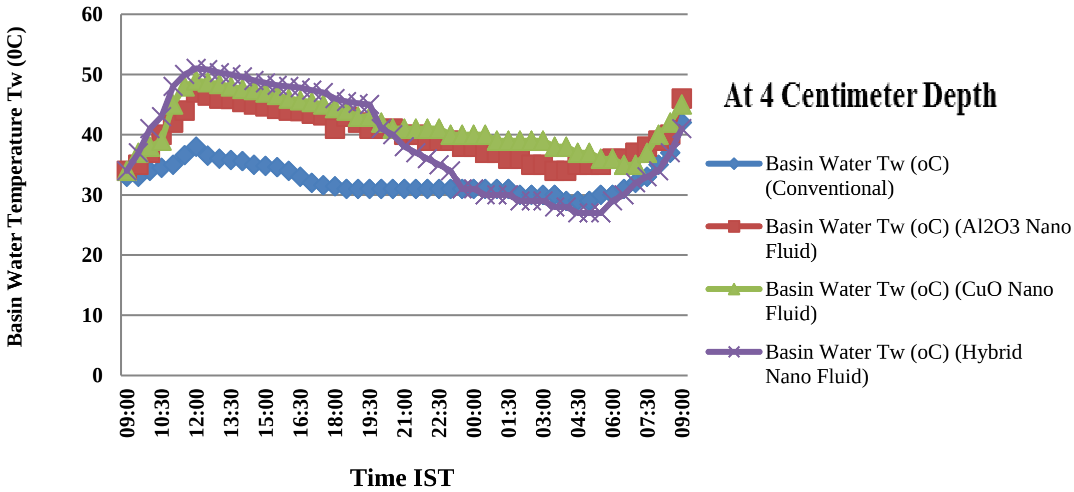

Fig. 10. Basin water temperature (Tw) at 4 cm water depth

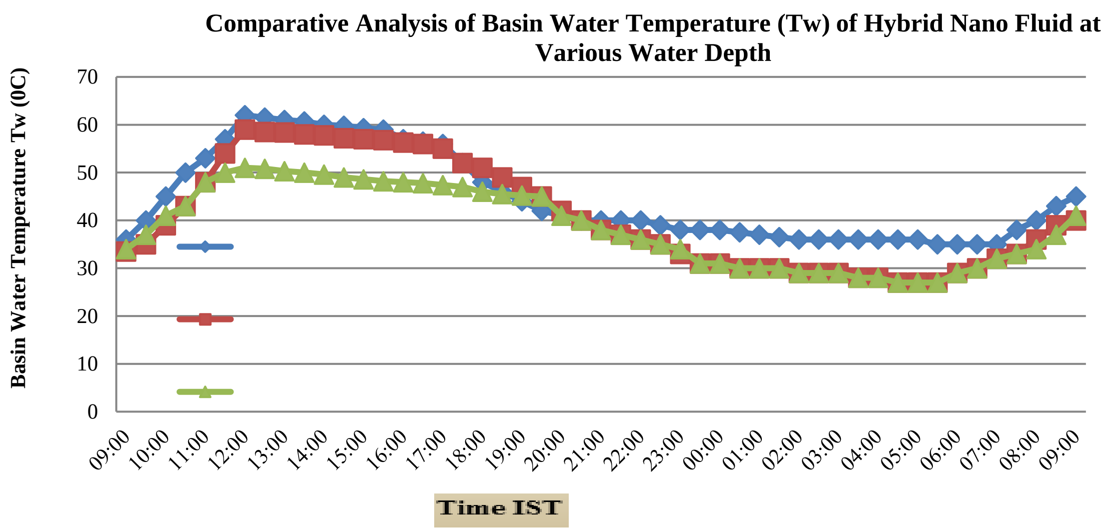

Fig. 11. Consolidated maximum basin water temperature (Tw) of Hybrid Nano Fluid at various water depths

At 2 cm water depth, the trend depicts that hybrid nano fluid achieves maximum basin temperature of 335 K at 12:00 AM while for others like conventional, Al_2O_3 and CuO attain basin temperature of 332 K, 331 K and 333 K at 12:00 AM respectively. Similarly at 3 cm, hybrid nano fluid achieves maximum basin temperature of 332 K at 12:00 AM while others like conventional, Al_2O_3 and CuO attained basin temperature of 318 K, 326 K and 328 K at 12:00 AM. Also, for 4 cm water depth, hybrid nano fluid achieves maximum basin temperature of 324 K at 12:00 AM while for others like conventional, Al_2O_3 and CuO attain basin temperature of 311 K, 310 K and 322 K at 12:00 AM.

Therefore, from above analysis it is clearly shown that hybrid nano fluid attains maximum basin water temperature 335 K at 2 cm water depth (from Fig. 11). The temperature in the basin steadily drops as the depth of the water rises. The increased depth of the basin water mass causes it to occur because of its high thermal inertia. Hence hybrid nano fluid performs significantly more effective than other nano fluid based solar stills. This will increase not only the efficiency of solar still but also enhance productivity of solar still.

4.4. Variation In Heat Transfer Coefficients Hourly for Various Water Depths in Basins

4.4.1 Variance in Heat Transfer Coefficients In 2cm Basin Water Depth

Since Fig. 12-14 show the heat transfer coefficients (i.e., conductive, evaporative and radiative) from water inside basin to glass cover in single slope conventional type and nano fluid based (at 1% concentration) still, at 2 cm basin water depth. The trend depicts that evaporative heat transfer coefficients (hewg) from water in basin to glass surface continuously enhances with respect to time as well as attains maximum at 12:00 PM. After that it decreases simultaneously. In this trend, a comparative analysis is made between conventional type and nano fluid based like Al_2O_3 nano fluid, CuO nano fluid as well as hybrid nano fluid of Al_2O_3 and CuO (50:50) at 1% concentration. It focuses on the fact that at 2 cm basin water depth, the highest amount attained during testing of evaporative heat transfer coefficient (hewg) is 9.98 W/m^2 K for conventional type, 25.59 W/m^2 K for Al_2O_3 nano fluid, 28.87 W/m^2 K for CuO nano fluid and 32.25 W/m^2 K for hybrid nano fluid based solar still at 12:00 PM.

Likewise experimental value of conductive heat transfer coefficients (hcwg) is 1.06 W/m^2 K for conventional type, 2.28 W/m^2 K for Al_2O_3 nano fluid, 2.46 W/m^2 K for CuO nano fluid and 2.63 W/m^2 K for hybrid nano fluid based solar still at 12:00 PM and radiative heat transfer coefficients (hrwg) is 7.46 W/m^2 K for conventional type, 7.73 W/m^2 K for Al_2O_3 nano fluid, 7.80 W/m^2 K for CuO nano fluid and 8.28 W/m^2 K for hybrid nano fluid based solar still at 12:00 PM respectively. In the above analysis it is clearly shown that heat transfer of hybrid nano fluid has maximum value compared to others. Due to this reason rate of evaporation of basin water is enhanced more in hybrid nano fluid based still at 2 cm water depth.

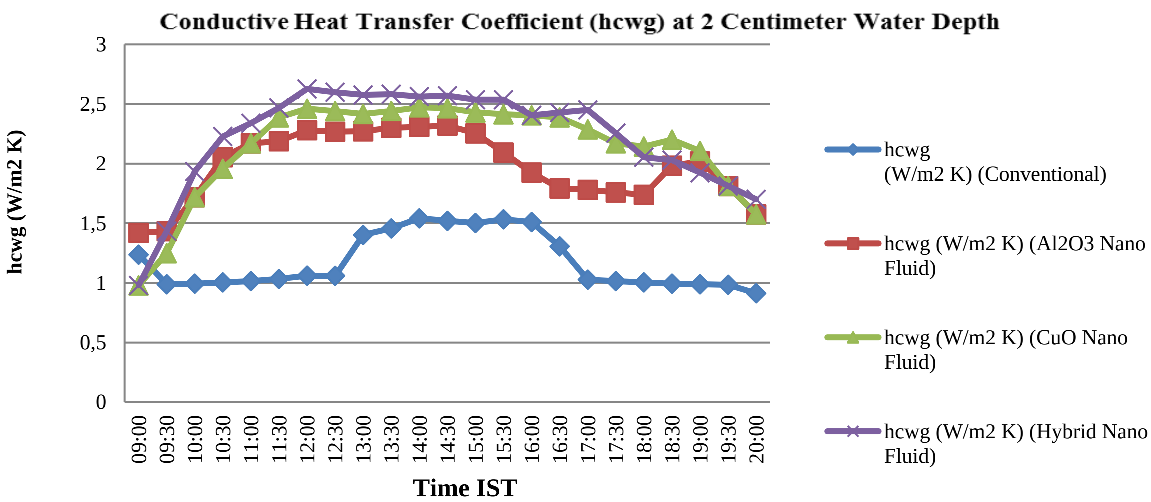

Fig. 12. Conductive heat transfer coefficient (hcwg) for 2 cm water depth

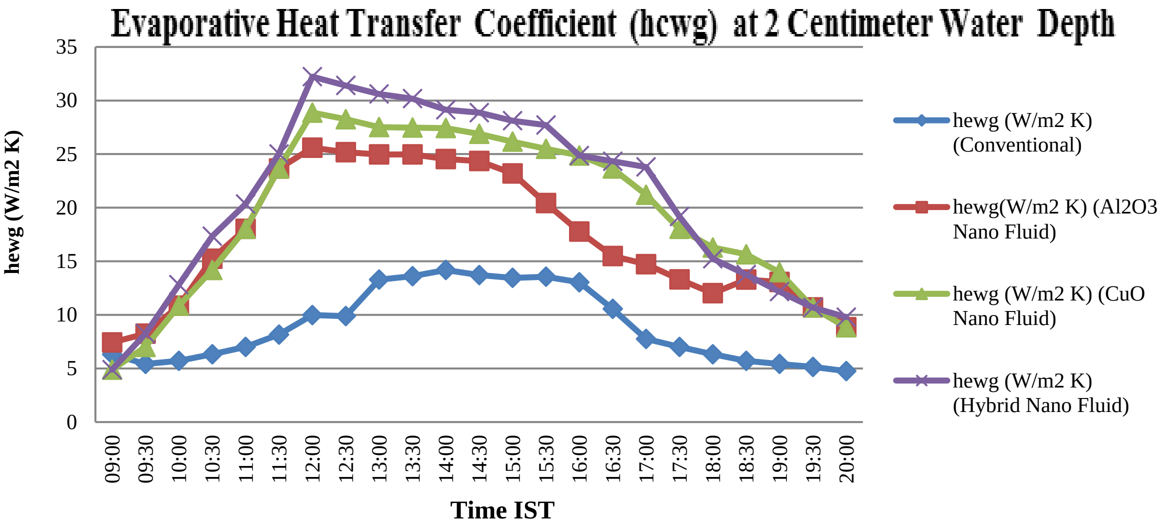

Fig. 13. Evaporative heat transfer coefficient (hewg) for 2 cm water depth

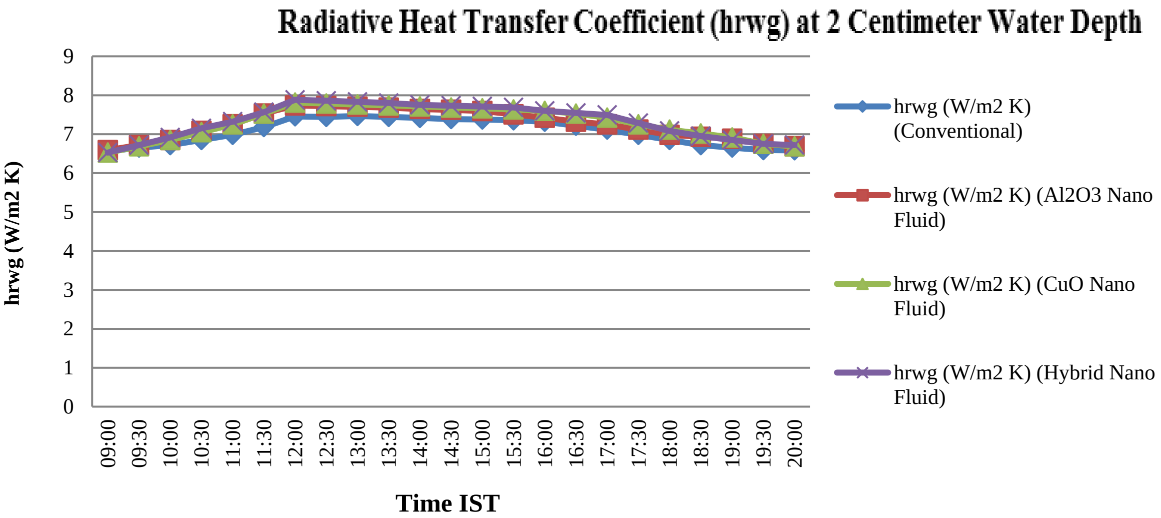

Fig.14. Radiative heat transfer coefficient (hrwg) for 2 cm water depth

4.4.2 Variance of Heat Transfer Coefficients For 3cm Basin Water Depth

Fig. 15-17 show the heat transfer coefficients (i.e., conductive, evaporative and radiative) from water inside basin to glass cover in single slope conventional type and nano fluid based (at 1% concentration) solar still, at 3 cm basin water depth. In this experiment, a comparison is made between conventional type and water based nano fluid like Al_2O_3, CuO as well as hybrid nano fluid of Al_2O_3 and CuO (50:50) at 1% concentration.

In this experiment, at 3 cm water depth, maximal experimental amount of evaporative heat transfer coefficient (hewg) is 7.76 W/m^2 K for conventional type, 11.59 W/m^2 K for Al_2O_3 nano fluid, 15.75 W/m^2 K for CuO nano fluid and 23.06 W/m^2 K for hybrid nano fluid based solar still at 12:00 PM. Similarly conductive heat transfer coefficients (hcwg) are 1.02 W/m^2 K for conventional type, 1.08 W/m^2 K for Al_2O_3 nano fluid, 1.38 W/m^2 K for CuO nano fluid and 1.78 W/m^2 K for hybrid nano fluid based solar still at 12:00 PM and radiative heat transfer coefficients (hrwg) is 7.11 W/m^2 K for conventional type, 7.66 W/m^2 K for Al_2O_3 nano fluid, 7.77 W/m^2 K for CuO nano fluid and 7.98 W/m^2 K for hybrid nano fluid based solar still at 12:00 PM respectively. In this analysis it focuses that the heat transfer coefficients of hybrid nano fluid have maximum values compared to others.

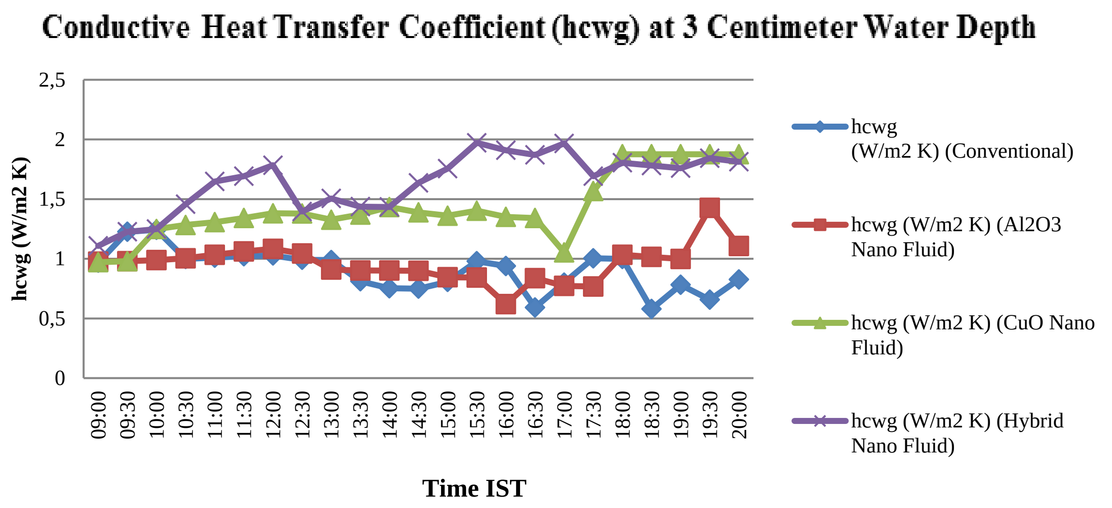

Fig. 15. Conductive heat transfer coefficient (hcwg) for 3 cm water depth

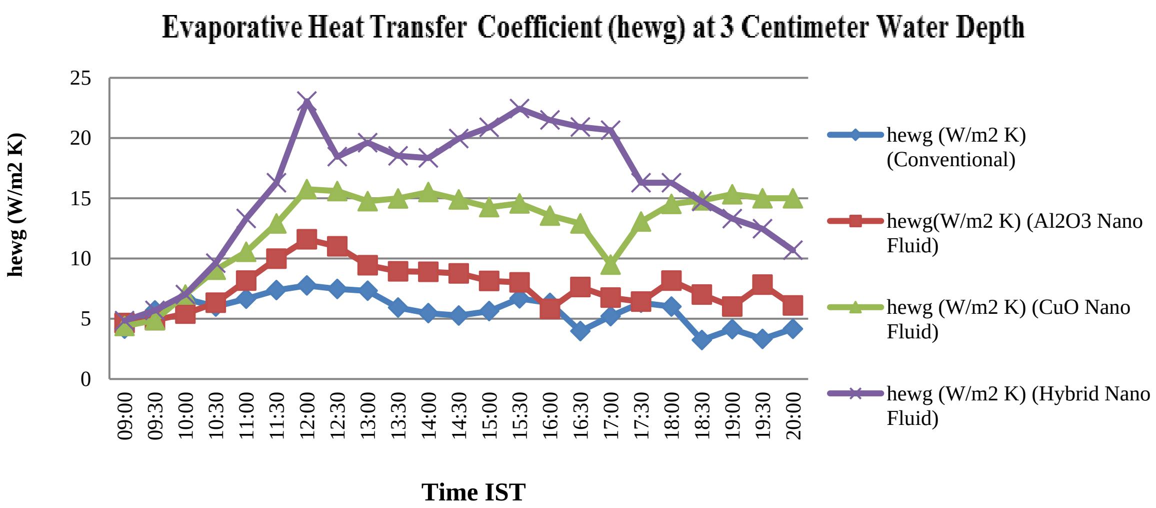

Fig. 16. Evaporative heat transfer coefficient (hewg) for 3 cm water depth

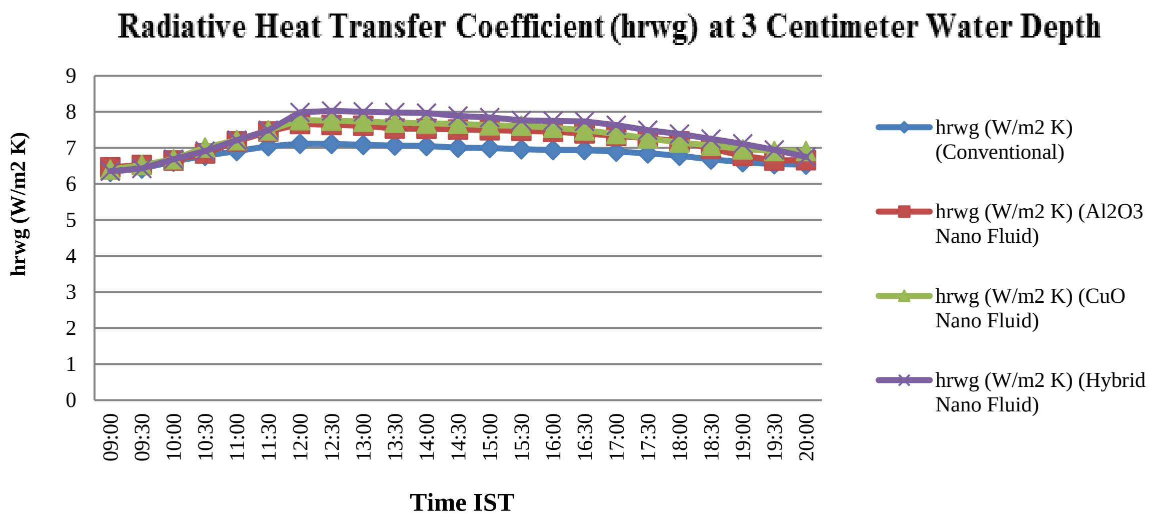

Fig. 17. Radiative heat transfer coefficient (hrwg) for 3 cm water depth

4.4.3 Variation of Heat Transfer Coefficients For 4cm Water Depth

In Fig. 18-20 show the heat transfer coefficients (i.e. conductive, evaporative as well as radiative) from water inside basin to glass surface in single slope conventional type and nano fluid based (at 1% concentration) solar still, at 4 cm water depth inside basin. This experiment shows comparative study of conventional type and water based nano fluid like Al_2O_3, CuO as well as hybrid nano fluid of Al_2O_3 and CuO (50:50) at 1% concentration.

At 4 cm basin water depth, maximal experimental value of evaporative heat transfer coefficient (hewg) is 5.42 W/m^2 K for conventional type, 8.58 W/m^2 K for Al_2O_3 nano fluid, 11.67 W/m^2 K for CuO nano fluid and 12.90 W/m^2 K for hybrid nano fluid based solar still at 12:00 PM. Similarly conductive heat transfer coefficients (hcwg) is 0.988 W/m^2 K for conventional type, 1.04 W/m^2 K for Al_2O_3 nano fluid, 1.32 W/m^2 K for CuO nano fluid and 1.34 W/m^2 K for hybrid nano fluid based solar still at 12:00 PM and radiative heat transfer coefficients (hrwg) is 6.65 W/m^2 K for conventional type, 7.25 W/m^2 K for Al_2O_3 nano fluid, 7.35 W/m^2 K for CuO nano fluid and 7.49 W/m^2 K for hybrid nano fluid based solar still at 12:00 PM respectively. In this analysis it is clearly mentioned, the heat transfer coefficients of hybrid nano fluid have maximum value compared to other solar still.

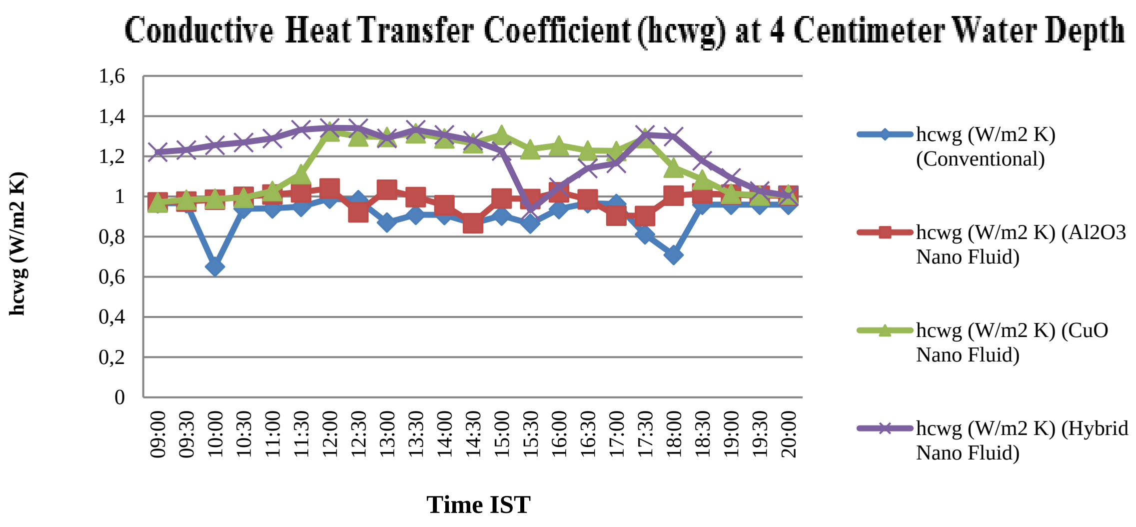

Fig. 18. Conductive heat transfer coefficient (hcwg) for 4 cm water depth

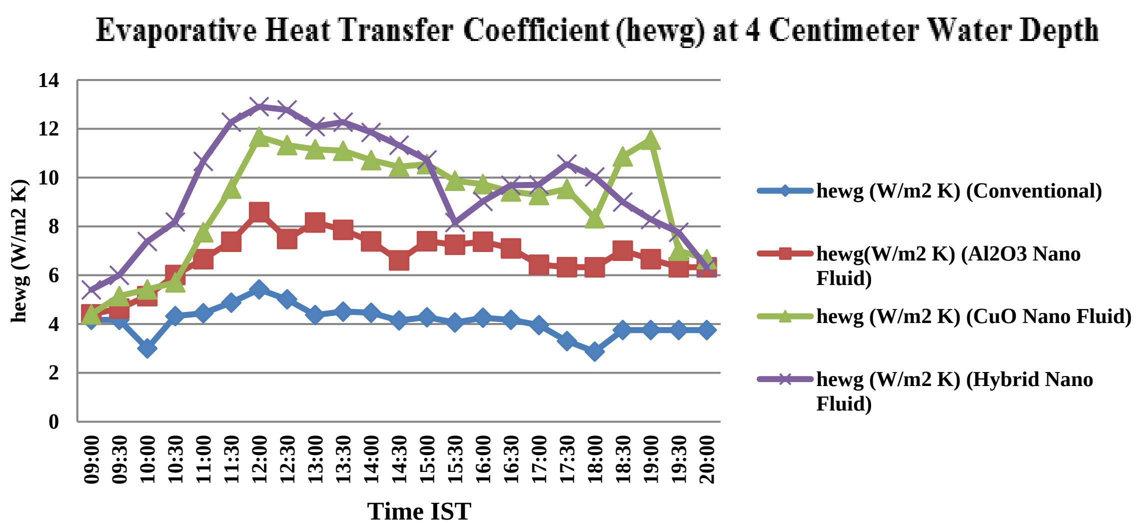

Fig. 19. Evaporative heat transfer coefficient (hewg) in 4 cm water depth

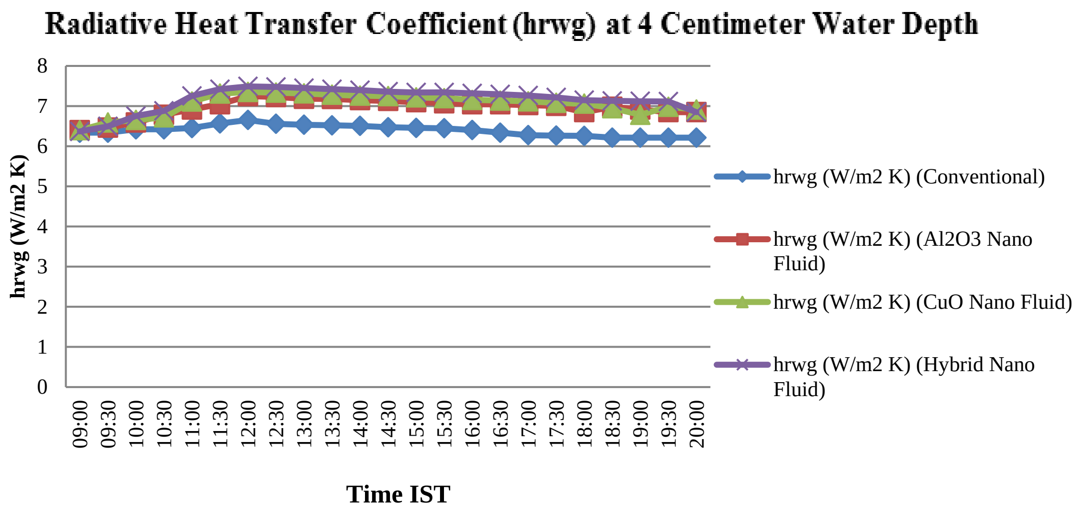

Fig. 20. Radiative heat transfer coefficient (hrwg) for 4 cm water depth

4.4.4 Comparative Analysis of Heat Transfer Coefficients for Hybrid Nano Fluid at Different Water Depth

This graph shows comparative analysis of heat transfer coefficients (i.e., conductive, evaporative as well as radiative) for hybrid nano fluid at different water depth such as 2, 3 and 4 cm respectively. The trend depicts, hybrid nano fluid, at 2 cm water depth has higher value of heat transfer coefficients compared to 3 cm and 4 cm water depth. The evaporative heat transfer coefficient (hewg) enhances continuously with respect to time and obtains maximal value at 12:00 PM for all water depths in basin from 2 cm to 4 cm basin water depth. After 12:00 PM it continuously decreases. The highest value of evaporative heat transfer coefficient (hewg) is 32.23 W/m2 K at 2 cm water depth and minimum value is 12.90 W/m2 K at 4 cm water depth.

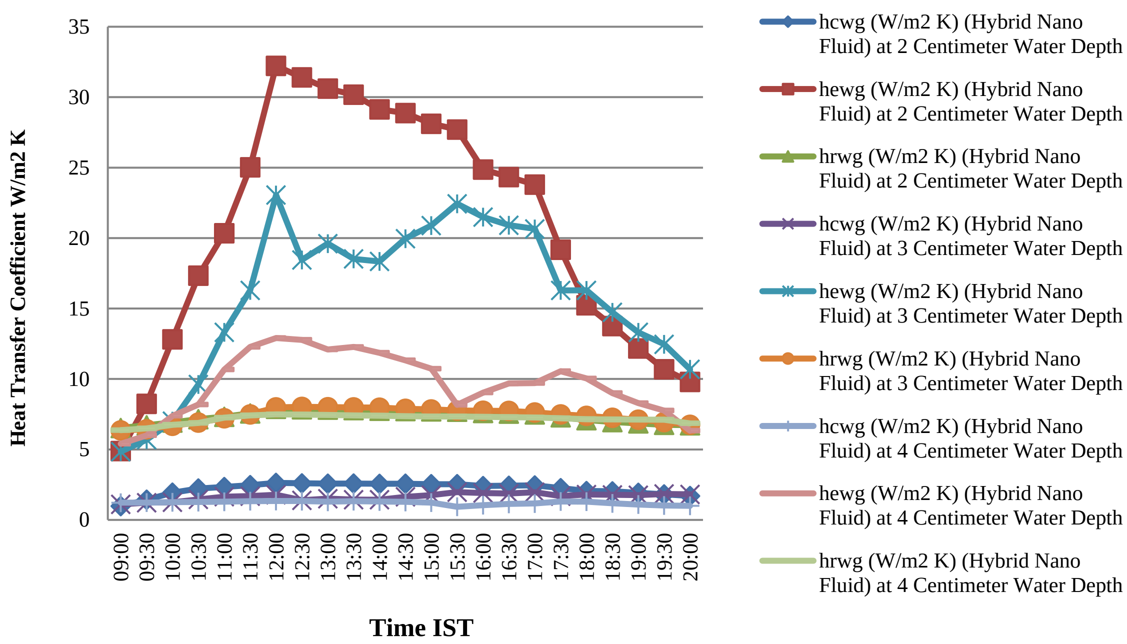

Fig. 21. Comparative analysis of heat transfer coefficients for hybrid nano fluid at different water depth

It happens because, as the depthless of basin water increases, so does the volume of water inside, increasing the phenomenon of water's thermal inertia and, ultimately, the rate at which the basin's water evaporates. Since Fig. 21, also illustrates the maximum value of conductive heat transfer coefficients (hcwg) as well as radiative heat transfer coefficients (hrwg) are 2.62 W/m^2 K and 8.28 W/m^2 K at 2 cm water depth and minimum value is 1.34 W/m^2 K and 7.49 W/m^2 K at 4 cm water depth.

4.5. Variance of total yield hourly for distinct water depths

4.5.1 Comparative Analysis of Total Yield for Different Solar Stills At 2cm Basin Water Depth

Fig. 22 indicates comparative analysis of total yield for different solar stills at 2 cm water depth. The graph depicts that Al_2O_3 and CuO based hybrid nano fluid performs superior than other solar stills like conventional, Al_2O_3 and CuO based nano fluid solar stills. It is clearly shown that hybrid nano fluid gives maximum distillate of 689 ml whereas 605 ml for CuO, 570 ml for Al_2O_3 and 530 ml for conventional solar still. This illustrates that hybrid nano fluid of (Al_2O_3 and CuO of 50:50 at 0.1% concentration) improves distillate.

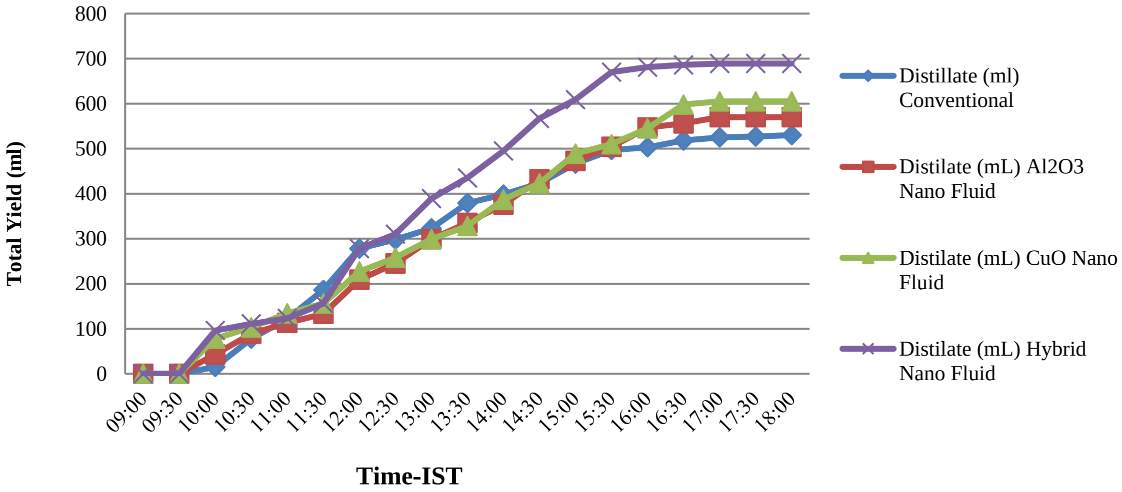

Fig. 22. Comparative analysis of distillate between different solar stills at 2 cm water depth

4.5.2 Comparison of Distillate for Different Solar Stills At 3cm Basin Water Depth

Fig. 23 illustrates comparison of total yield between different solar stills at 3 cm water depth. It is clearly shown that hybrid nano fluid gives maximum distillate of 589 ml whereas 545 ml for CuO, 456 ml for Al_2O_3 and 396 ml for conventional solar still.

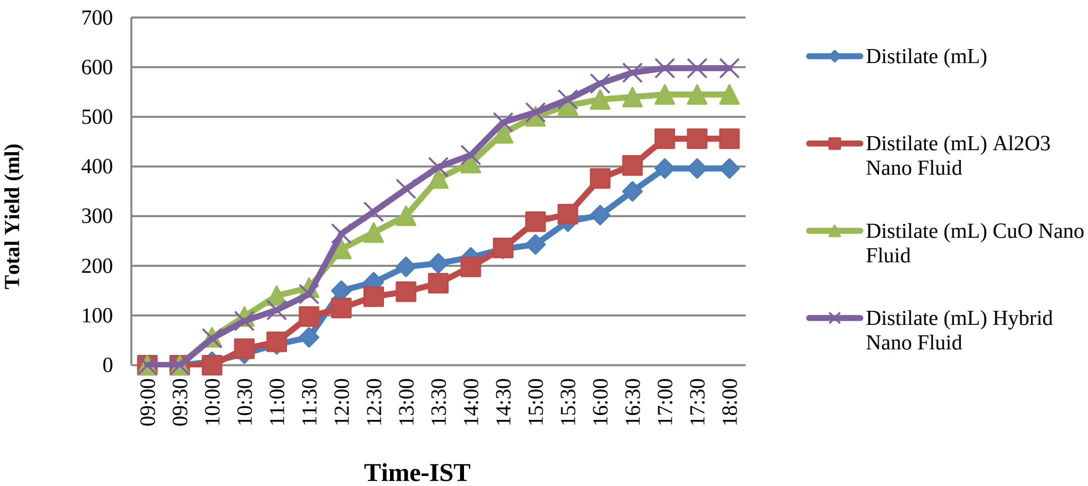

Fig. 23. Comparative analysis of distillate between different solar stills at 3 cm water depth

4.5.3 Comparison of Distillate for Different Solar Stills At 4 Cm Basin Water Depth

Fig. 24 illustrates comparative analysis of total yield between different solar stills at 4 cm water depth. As per the graph, by examining hybrid nano fluid gives maximum distillate of 488 ml whereas 435 ml for CuO, 305 ml for Al_2O_3 and 258 ml for conventional solar still at 4 cm basin water depth.

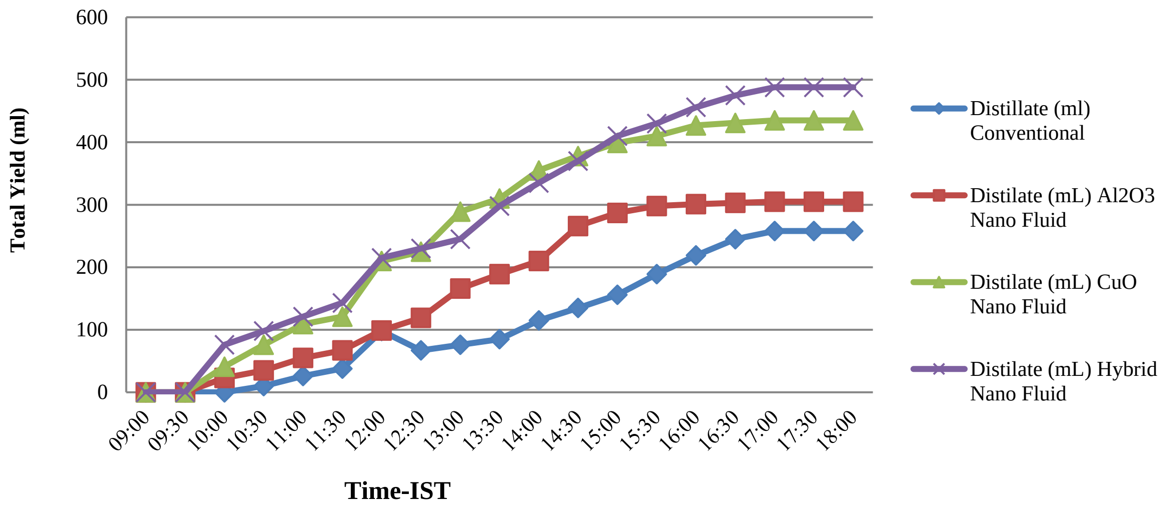

Fig. 24. Comparative analysis of distillate between different solar stills at 4 cm water depth

4.5.4 Comparison of Total Yield for Hybrid Nano Fluid Based Solar Stills at Different Water Depth

In Fig. 25-26, a comparative analysis is carried out between hybrid nanofluids at different water depth (2cm, 3cm and 4cm), as per this analysis it is clearly shown that hybrid nanofluid at 2 cm basin water depth gives maximum distillate compared to hybrid nanofluid of 3 and 4 cm basin water depth. Here maximum total yield 689 ml is obtained for hybrid nanofluid at 2 cm basin water depth whereas minimum yield 488 ml received at 4 cm water depth. Experimentally examined, that hybrid nano fluid based solar still performs well at 2 cm basin water depth, gives significant amount of total yield due to enhanced evaporation rate of brackish water from basin.

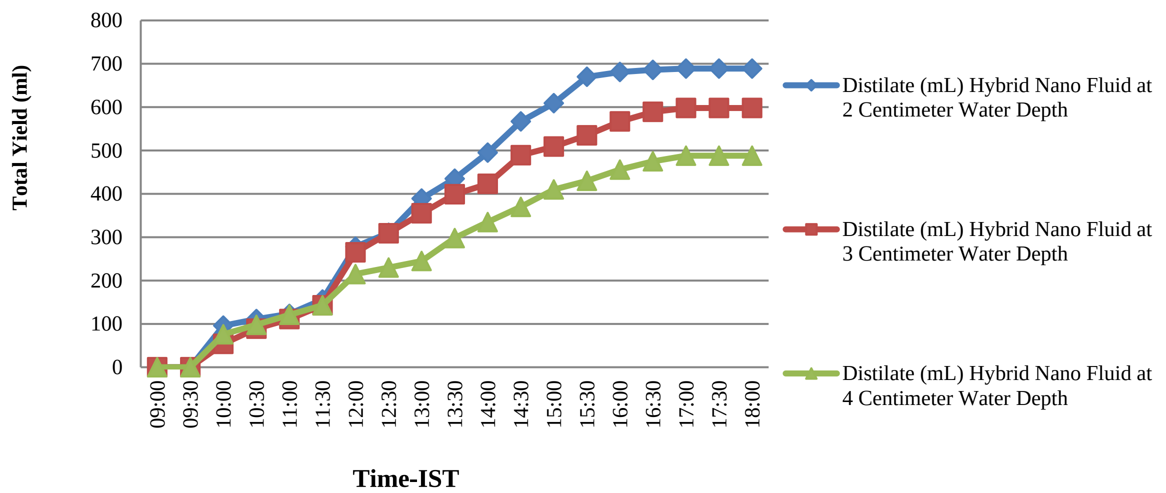

Fig. 25. Comparative Analysis of Distillate for hybrid nano fluid based solar stills at different water depth (2cm, 3cm and 4cm)

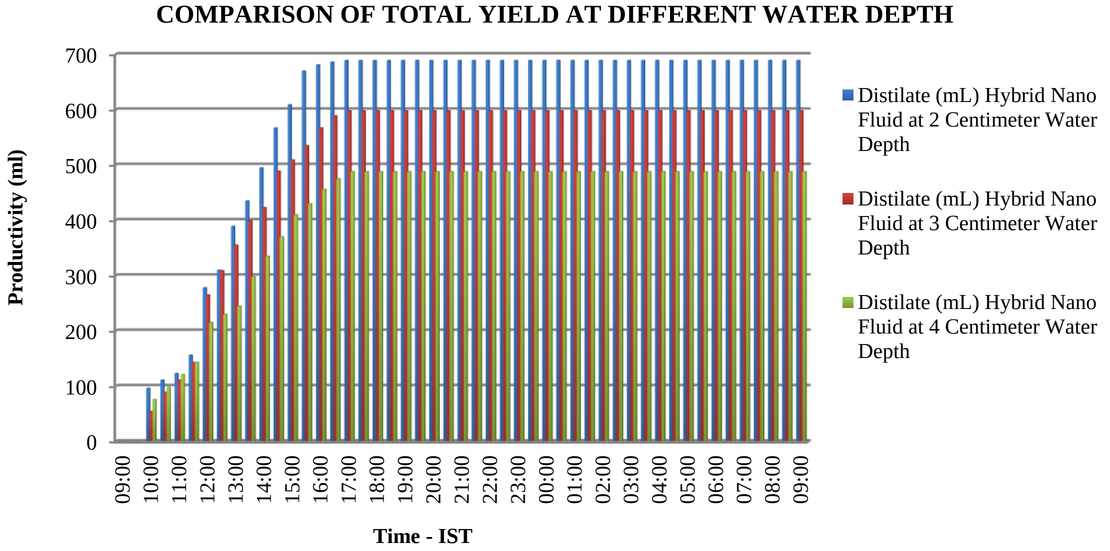

Fig. 26. Bar diagram of distillate at different water depth (2cm, 3cm and 4cm)

5. Conclusions

This research work has been accomplished by conducting experimental analysis of effect of basin water depth for 2 cm, 3 cm and 4 cm by using nano fluid and Al_2O_3 – CuO based hybrid nano fluid at a concentration of 0.1%, stored in silver (Ag) cylinder. It examines the effect of basin water depth on solar still productivity which led to the following conclusions:

- A comparative analysis is done on heat transfer coefficients (i.e. conductive, evaporative and radiative) for hybrid nano fluid, nano fluid and conventional type still at different basin water depth 2 cm, 3 cm and 4 cm respectively. The result shows that hybrid nano fluid, at 2 cm basin water depth has maximum value of heat transfer coefficients (i.e. conductive, evaporative and radiative) compare to 3 cm and 4 cm water depth.
- The highest amount of evaporative heat transfer coefficients (hewg) is 32.23 W/m^2 K at 2 cm water depth while 23.06 W/m^2 K at 3 cm water depth and 12.90 W/m^2 K at 4 cm water depth respectively.
- It is analyzed that convective and radiative heat transfer coefficient values are found to be significantly lower than evaporative heat transfer coefficient values. The maximum value of conductive heat transfer coefficients (hcwg) and radiative heat transfer coefficients (hrwg) are 2.62 W/m^2 K and 8.28 W/m^2 K at 2 cm water depth and minimum value is 1.34 W/m^2 K and 7.49 W/m^2 K at 4 cm water depth respectively.
- The results indicate that as the Al_2O_3 – CuO (50:50 ratios) based hybrid nano fluid gives superior performance compared to mono nano fluid and conventional type still at different basin water depth. In this experiment, with hybrid nano fluid, total yield 689 ml is obtained at 2 cm basin water depth, while 598 ml and 488 ml received for 3 cm and 4 cm water depth at 0.1% concentration. It is evident that when the depth of the basin water in a solar still increases, the output of distillate drops.
- Considering the findings of this research, it can be concluded that employing hybrid nano fluid, stored at silver (Ag) cylinder, on solar still at 2 cm basin water depth and 0.1% concentration enhanced approaches is effective for analyzing and optimizing of solar distillation system.

Acknowledgement

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Nomenclature

T_a	Ambient temperature (^{0}C)
I(t)	Solar Intensity (W/m^2)
T_{gi}	Temperature of glass inner surface (^{0}C)
Q_{cbw}	Convective heat transfer rate from basin liner to water (W/m^2)
h_{cbw}	Convective heat transfer coefficient from basin liner to water (W/m^2 K)
Q_{cwg}	Convective heat transfer rate from water to glass cover (W/m^2)
h_{cwg}	Convective heat transfer coefficient from water to glass cover (W/m^2 K)
Q_{ewg}	Evaporative heat transfer rate from water to glass cover (W/m^2)
h_{ewg}	Evaporative heat transfer coefficient from water to glass cover (W/m^2 K)
Q_{rwg}	Radiative heat transfer rate from water to glass cover (W/m^2)
h_{rwg}	Radiative heat transfer coefficient from water to glass cover (W/m^2 K)
Q_{twg}	Total heat transfer rate from water to glass cover (W/m^2)
Q_{tga}	Total heat transfer rate from glass cover to atmosphere (W/m^2)
Q_{tba}	Total heat transfer from basin liner to ambient (W/m 2)
h_{tba}	Total heat transfer coefficient from basin liner to ambient (W/m 2 °C)
h_{twg}	Total heat transfer coefficient from water to glass cover (W/m^2 K)
P_{gi}	Partial vapour pressure at glass inner surface temperature (N/m2)
C_w	Specific heat of water in solar still (J/kg °C)
m_w	Mass of water
T_w	Temperature of water (^{0}C)
P_w	Partial vapour pressure of water (N/m^2)
Cm	Centimeter

Greek

ε	Emissivity
σ	Stefan Boltzmann constant
α	Absorptivity
α'_g	The proportion of solar radiation that a glass cover absorbs
α'_w	The proportion of solar radiation that basin water absorbs
α'_b	The proportion of solar radiation that basin liner absorbs
τ	Transmissivity

Subs scripts

B	Basin
g	Glass
r	Radiative
gi	Glass inner surface
w	Water
Ag	Argentum (Silver)
E	Evaporation
M	Mass (kg)

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