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14. Fret Effect for Enrichment of Solar Energy Absorption by ZnO Nanoparticles/Activated Carbon Incorporated Single Slope Corrugated Wick Type Solar Distiller with Phase Change Material

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Figure 14.1: Nanoparticles

Abstract:

Saline water flowing through the wick material of single slope ridged wick-type solar still is acquaint with ZnO nanoparticles (Figure 14.1) and activated carbon combined in equal ratio to enhance the absorption of energy from the sun and transference to molecules of water by Forster Resonance Energy Transfer mechanism. Phase change material of paraffin is placed beneath the corrugated wick spread on the sloping surface of the solar still for the enrichment of production of pure water. The energy transfer between the nanoparticles/activated carbon to water is analyzed using FRET mechanism and studied.

The rate of evaporation from evaporating water into the condensing surface has increased to a larger extent with respect to the conservative wick type solar still. Average evaporative heat transfer of 157 W/m^2 is obtained for the proposed still for one of the pronounced sunny days in the month of May 2022 with average daily distillate yield of 5.123 l/m^2day over 24 hr cycle and daily average efficiency of 42.53%. It is found the efficiency is increased by 42% compared to the wick type solar still. The phase change material of paraffin has increased the night time production by releasing the sensible heat absorbed during daytime into the water molecules at night-time. The dispersion of energy between the particle components have been studied using FRET mechanism.

Keywords:

FRET mechanism, activated carbon, ZnO nanoparticles, paraffin

14.1 Introduction:

Education is an unquestionable privilege. It helps to form opinions and makes people less vulnerable to undesirable influences. An educated individual makes a responsible and dutiful citizen and also a compassionate social being. Thus, an educated society strives for excellence and creates an efficient society. However, to derive the benefits of education, an investment of both time and money becomes necessary. Individuals, being of different financial capabilities, sometimes find it difficult to invest the required resources. In a democratic setup, it therefore becomes the Government's responsibility to aid such investment. The pandemic which came in 2020 disrupted all such plans, both at the individual and administrative level. The education system which is the foundation structure for the demography of the economy was faced with a massive challenge of its continuity in the unprecedented time. The government had to fix this serious dilemma on how to arrest the spread of the coronavirus without compromising the education of the country. Due to the nationwide lockdown the government had closed down all the institutes of the country retarding all the learners of progressive education. Stopping education would risk a series of generations from advancing to a better future. Accordingly, the government, scholars, leaders, bureaucrats and policy makers were demanded to take the optimal decisions to mitigate this grave problem of saving the nation from falling to the face of illiteracy and slow economic development. Consequently, the government leveraged this occasion to come up with e-learning programs and rethought the conventional learning methods with these viable solutions. The paper is divided into 6 sections. Section-1 talks about the literature review. Section-2 points to the state of public finance in the country. It highlights how the budget is increasing but still lower than the target figure. Section-3 talks about the impact of COVID-19 in on the student's foreign education. Section-4 talks about the impact of loss of class hours and learning gaps created by the pandemic. Section-5 reveals the issue of learning gap among the instructors. Section-6 talks about alternative education during the pandemic.

Shanmugan *et al*. (2020) have coated the basin liner with TiO_2 nanoparticle mixed with Cr_2O_3 with various weight percentage ratio and characterized using SEM, FTIR and XRD. The proposed solar still is experimented in both winter and summer days in local climatic condition of KL University in Vijayawada.

It is observed that the still with the coatings has given good efficiency of 57.16% and 36.69% during summer and winter days. Gamal B. Abdelaziz *et al*. (2021) have experimented two solar stills with and without porous activated caron tubes to analyze the still for energy, exergy, environmental, enviroeconomic, exergyeconomic, exergoenvironmental and exergyenviroeconomic mode of view. It is observed that the still with porous activated carbon tube has pronounced performance in all the views with positive impact. Amrit Kumar Thakar *et al*. (2021a) have used reduced graphene oxide to coat the basin of solar still and sensible thermal storage material of activated carbon pellet to increase the output and related the results with conformist solar still. It is found that the proposed still has reduced the production cost by 15.5% not associated for conservative solar still and still with RGO alone. Amrit Kumar Thakar *et al*. (2021b) have integrated the parabolic trough with a solar still to preheat the sea water and used activated carbon pellet to be used as thermal energy storage material. The observed results have shown that the proposed solar still has given output which is 85% higher than conventional solar still with a payback period of 66 days. Arunkumar *et al*. (2022) have undergone a thorough review of the utilization of carbonized carbon obtained from natural green flora in solar distillation unit. Precise results obtained by various researchers have been presented with detailed explanation about the experiments for the information for future researchers in this field.

Further, Tuly *et al*. (2022) have examined solar still with double slope cover incorporated with the combination of fins, phase change materials, external condenser and wick materials for the performance. It is observed that the usage of the combination has produced distillate yield of 32.46% higher than the still with auxiliary arrangements used separately. Samish Mahendra Fale *et al.* (2022) have precisely presented the current scenario of the different designs of solar still by the scientists throughout the globe. In addition, many absorbing materials are also utilized to augment maximum absorption of solar radiation to improve the distillate output. Sangeetha *et al.* (2022) have undergone a study with U-shaped stair case basin solar still with various concentration of activated carbon prepared from magifera indica and celostia argentea with ZnO nanoparticles.

Thermodynamic analysis has been carried out by deriving Gibb's free energy equation for the thermal process and presented. It is found that the still has produced distillate yield of 14.921 l/m^2day with efficiency of 38.73%. Amrit Kumar Thakar *et al*. (2022c) have used activated carbon of different concentrations with the black paint to coat the absorber plate and examined the output. The concert of solar still is upgraded due to higher captivation of solar radiation by the activated carbon presented in the black paint coating of the absorber plate. Ramasamy Dhivagar *et al*. (2022) have undergone experiment with single slope solar still consist of rectangular and circular ceramic magnets in the basin and analyzed for energy and exergy. It is revealed that the still with rectangular ceramic magnet has pronounced performance due to the magnetization of saline water to produce distillate yield of 3.15 kg/m^2. Emad M.S El-Said *et al*. (2022) have utilized the carbon tube for humidification in humidification-dehumidification desalination system. The rate of air flowing is fixed as 0.01156 kg/s and allowed through the porous carbon tune and cooling system has produced distillate output of 6.12 kg/day with production cost of 0.01386 USD for liter of water. Modi *et al.* (2023) have thoroughly made a review on the usage of nanofluid and hybrid nanofluid in solar still and precise results obtained by various researchers is presented with future recommendations in this field. Hasan Mousa *et al*. (2019) have drafted a prototypical to govern the water temperature in solar still provided with phase change material.

The model is drafted with assumption of five zones including the change of phase of the material and validated with experimental results. Results obtained by the model is intact with the experimental output.

Rahul Agarwal and Krishna Deo Prasad Singh (2021) have used mixture of two acids (palmitic and Steric acid) in copper tubes cylinders and kept over the fiber made of steel wool in the basin of solar still to predict the efficacy of solar still with various height of water in the basin. It is found that the still with PCM in copper tube and cylinder has given efficiency of 41% due to the enhancement of irradiation from water to glass cover. Amer A. Saeed *et al*. (2022) have designed a new ridged drum solar still and used PCM doped with Ag nanoparticles. The amount of distilled water collected is 318% higher than other designs with the cost of 0.039$ per liter of water. Essa *et al*. (2022) have used phase change material, nanoparticle, rotating drum and parabolic concentrator in connection with solar still and studied the performance. It is found that, the revolution of 0.3 rpm of the drum with PCM in addition with parabolic concentrator has given highest thermal efficiency of 63%. Abdullah *et al*. (2021) have fabricated conventional, corrugated tray and flat tray solar stills incorporated with CuO nanoparticles and phase change material in the basin to study the performance. Results revealed that the corrugated tray solar still has produced higher efficiency which is 180% greater than the other solar still. Aswati Aditya Bachchan *et al*. (2021) have made a review about the phase change material and porous absorbing materials with fins and sponge in solar stills. Precise results of the researchers have been presented with indispensable explanation which will be useful for future researchers. Paraffin wax and floating wicks have been used in the basin solar still by Gurprinder Singh Dhindsa (2020) and studied the performance. The still has produced an output of 3.96 kg/m^2 which is 28.14% higher than the conventional solar still.

Rahul Agarwal and Krishna Deo Prasad Singh (2022) have combined organic PCM to obtain binary eeutic PCM joined with double slope solar still for experimentation. The proposed solar still has given efficiency of 30.42% whereas computational fluid dynamics gave 33.15%. Thus, simulation can be done using CFD for the still. Wissam H. Alwae *et al*. (2022) have conducted experiment with the single slope solar still modified by introducing copper heating coil, an external condenser and Ag/PCM. The solar still has given enhanced efficiency, distillate output and cost of producing 1 litre of water is 0.022$/l. Arivazhagan Sampathkumar and Sendhil Kumar Natarajan (2022) have introduced Agar-Agar fiber on the water surface of slope solar still and introduced microphase change material beneath the basin to enhance the productivity. It is found that agar-agar with micro PCM has produced distillate yield of 4.380 l/m^{2}day while for ordinary solar still produced 3.030 l/m^{2}day. Maridurai *et al*. (2022) have combined double slope basin solar still with water heater to preheat the water and phase change material for sensible heat storage to study the performance. Results revealed that the efficiency increases by 15% with flat plate collector and heat storage material. Erfan Hedayati-Mehdiabadi *et al*. (2022) have incorporated photovoltaic tube collector and phase change material with a double slope basin solar still to study the performance. The still has given output of 6.5 kg/m^{2}h. Roohollah Nakhaei *et al*. (2022) have conducted experiment with solar cell cosensitized with natural and synthetic dyes using FRET mechanism which explained the charge transfer from natural pigment to synthetic pigment. Results have been revealed the enhancement of efficiency of 2.9%. Yu Jin Jang *et al*. (2019) have undergone the performance of solar cell using the plasmonic and FRET effect to interpret the energy transfer between the light sensitive components. The study showed the enhancement of efficiency by 36% compared to ordinary effects. In the present work, ZnO nanoparticles are synthesized via green synthesis and activated carbon is prepared by carbonizing the mango tree wood followed by activation through NaOH. The mixture of nanoparticles and the activated carbon are taken in equal ratio and introduced into the saline water tank of single slope wick-type solar still. Further, the phase change material of paraffin wax is introduced beneath the corrugated wick surface and the heat energy liberated during the phase change in the evening is used for the evaporation process during nighttime. The FRET mechanism involved in the convection of heat energy from ZnO/Activated carbon to the saline water is discussed for the behavior of the system.

14.2 Design of Single Slope Corrugated Wick Type Solar Still:

The single slope corrugated wick-type solar still is designed which comprises of water tank joined with a sloped surface with a tilt angle of 15° using galvanized sheet which is fixed inside a plywood structure. The sloped surface and the tank have the measurement of 1m x 1m x 0.15m and 1m x 0.25m x 0.25m. The tank and the sloped surface have been welded and rivets are used to hold both rigid. The space sandwiched between the inside and outside enclosures is filled with glass wool with thermal conductivity of 0.00038W/mK to reduce the conduction losses.

The jute wick is made into corrugated shape by stitching over the thermocole and grooved surface behind the corrugated shape is filled with the phase change material of paraffin wax. ZnO/Activated carbon nanocomposite is mixed with mat black paint and using sprayer, jute wick is coated homogeneously without affecting the pores which is utilized for capillary action. The drainage channel for distilled water is secure at the underlying side of the condensing glass cover which closes the solar still. Calibrated Iron-Constantan thermocouple is fixed at the regular intervals for the measurement of the temperature of the wick surface. Sine there is no temperature gradient of the condensed glass cover, a single thermocouple is fixed at the center of the glass cover to measure the condensing glass cover temperature. Figure 14.1 represents the photograph of the proposed solar still with solar radiation monitor.

Figure 14.2: Experimental Solar Still

14.2.1 Synthesis of Activated Carbon:

Arecanut shells have been collected and dried in a shadow region for more than two days for the complete removal of moisture content from the shells. The dried shells have been burnt to get carbonized carbon and confirmed for the complete carbonization of all the shells. The carbonized shells have been crushed into power using mortar and pestle to avoid the agglomeration of carbonized carbon. The carbonized shells are subjected for the treatment with NaOH to get the activated carbon. The NaOH is used to reduce the size of the carbonized carbon into activated carbon by reducing the size of the particle. Figure 14.2 represents the process of synthesis of activated carbon and subjected for the XRD spectroscopy for the determination of the grain size. Figure 14.3 represents the XRD spectroscopy of the activated carbon and it is found that the particles are amorphous in nature with broad peak obtained at 24°. Due to the amorphous nature of the material, 0.9 shape factor has been used in the Debye-Scherer formula and calculated the size of the activated carbon particle as 89.7nm. SEM image of the particles have been taken and depicted in Figure 14.5 and it is found that it resembles structure of flakes with the pores on the surface. Therefore, it has large surface area to hold the impurities in the saline water. The presence of carbon is confirmed with EDX spectroscopy and it recommends the concentration of the activated carbon particles with small fraction of oxygen.

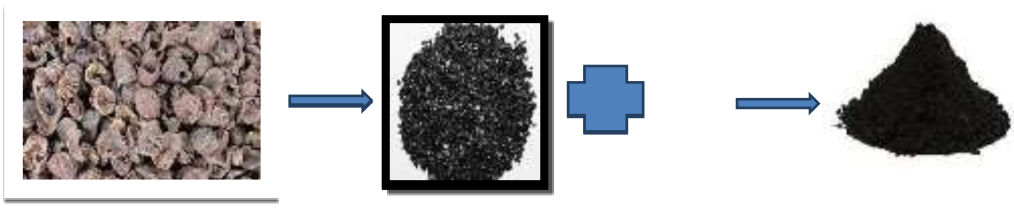

Figure 14.3: Process for the Synthesis of Activated Carbon from Arecanut Shell

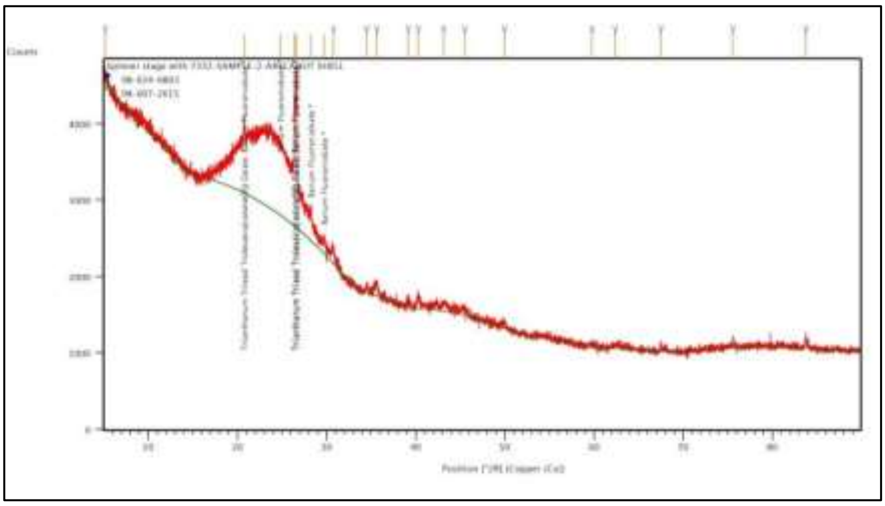

Figure 14.4: XRD Spectroscopy of the Activated Carbon from Arecanut Shell

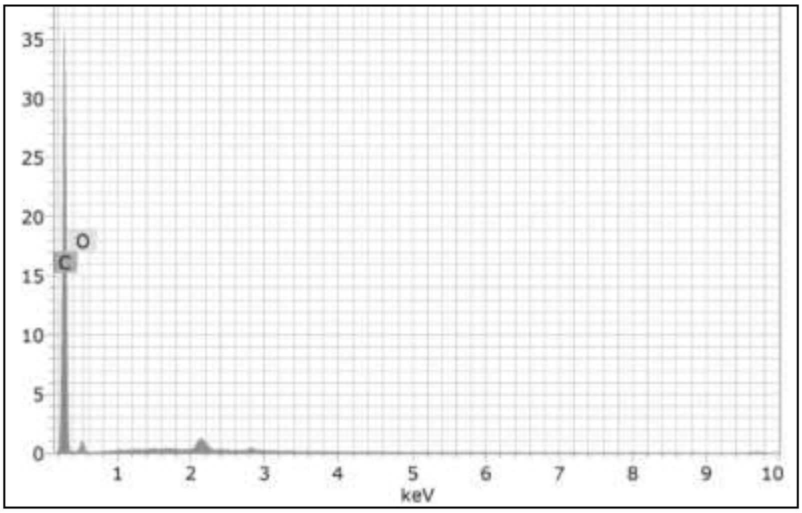

Figure 14.5: EDAX Spectrum of Activated Carbon from Arecanut Shell

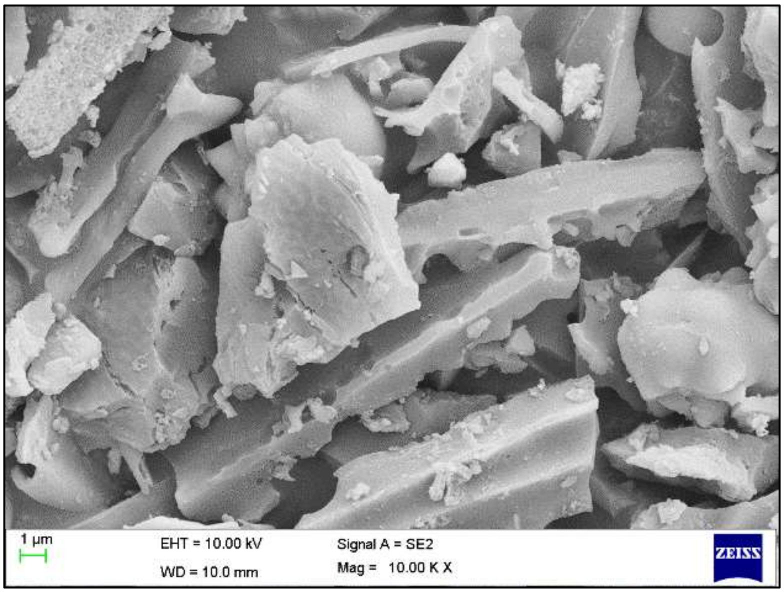

Figure 14.6: SEM Image of Activated Carbon from Arecanut Shell

14.2.2 ZnO Nanoparticles:

ZnO nanoparticles are bought from sigma Aldrich with size of 89nm and bandgap of 3.9eV bandgap. The nanoparticles have large surface area to undergo high photocatalytic activity.

ZnO nanoparticles and activated carbon are mixed in equal ratio to give a nanocomposite of ZnO/Activated carbon such that the photocatalytic activity of nanoparticles and adsorption/absorption property of the activated carbon has significant impact on the performance of single slope wick-type solar still.

14.3 Results and Discussion:

14.3.1 Experiment and FRET Mechanism:

The experiment has been conducted in the month of May 2022 in Andhra Pradesh with the proposed solar still with and without the nanocomposite of ZnO/Activated carbon. During the summer days, experiment is conducted with the simultaneous measurement of solar radiation and ambient temperature using Emcon Solar radiation monitor and digital thermometer. To find the advantage of FRET mechanism, the observations of two typical days (14.05.2022 & 17.05.2022) have been selected in which experiment is conducted with and without ZnO/Activated Carbon. The climatic parameters have been recorded and graph is plotted in Figure 14.6. From the figure, it is clear that, experiments carried out in the peak sunny days have similar conjoint trend of values of climatic parameters.

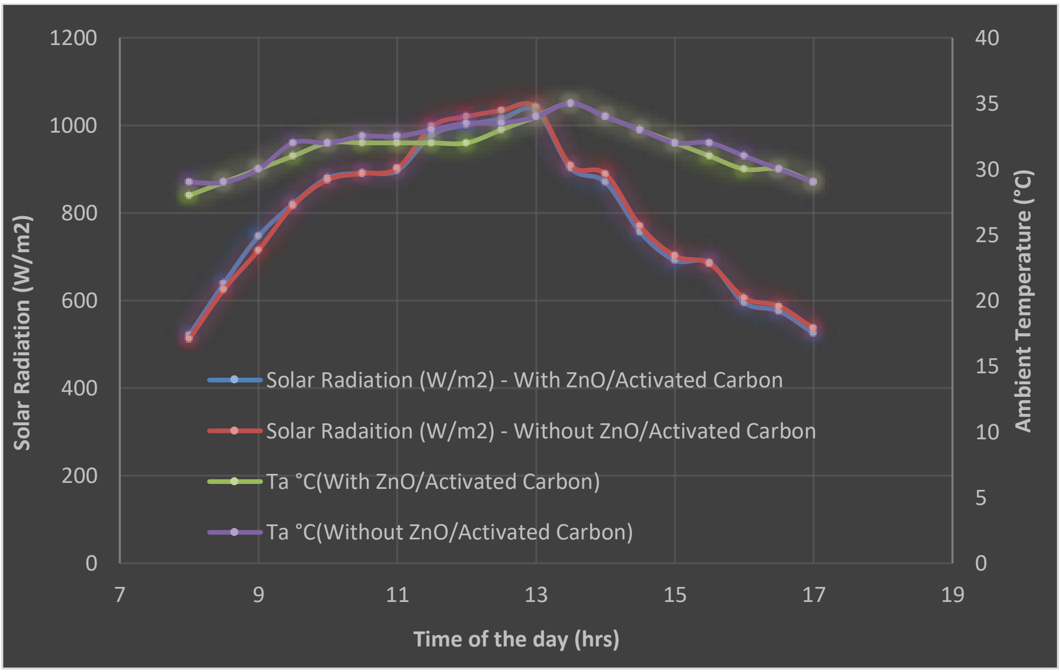

Figure 14.7: Solar Radiation and Ambient Temperature on 14.05.2022 and 17.05.2022

14.3.2 Energy Transfer by FRET Mechanism:

The solar radiation transmitted through the glass cover and reaches the wick surface and gets adsorbed and absorbed by activated carbon and ZnO nanoparticles. The activated carbon has the property of adsorbing the impurities from the saline water and therefore the impurities will be diminished. The amount of energy adsorbed and absorbed by the activated carbon and ZnO nanoparticles is represented in Figure 14.7. The energy adsorbed and absorbed is maximum during the 30 minutes time interval between 12.30 pm and 1.00pm. In the meantime, the energy is also absorbed by ZnO nanoparticles directly as well as through the activated carbon due to FRET mechanism.

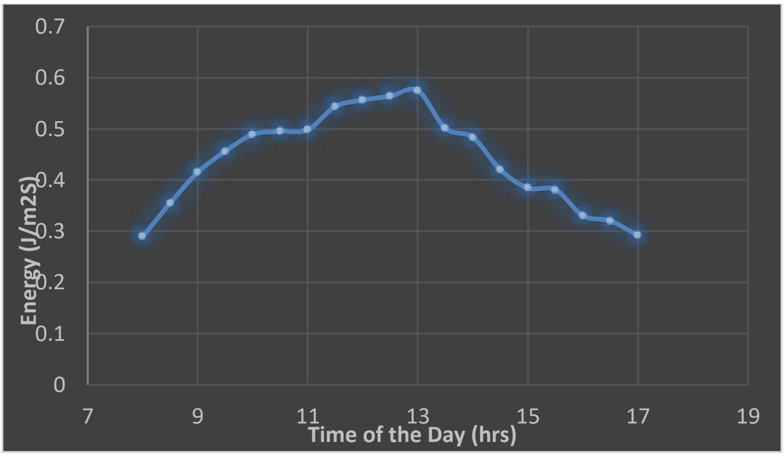

Figure 14.8: Energy Adsorbed and Absorbed by Activated Carbon and ZnO Nanoparticles

The Energy is then transferred to the water molecules in the floating and tilted wick surface again by FRET mechanism. The schematic representation of the FRET mechanism has been depicted in Figure 14.8.

The presence of ZnO/Activated carbon has influenced the evaporation process to a larger extent due to adsorption and absorption of solar radiation. The adsorption by activate carbon has decreased the impurities in the water and energy is transferred to the ZnO followed the energy transfer to the water molecules. Further, energy available due to ZnO/Activated carbon is accomplished with the absorption by phase change material paraffin which is placed beneath the corrugated wick i.e. floating wick on the water surface of the water tank. During the peak sunny hours, energy is continuously utilized for the phase change of paraffin wax throughout the day. In the evening hours, again the phase of the paraffin wax is changed with the release of energy absorbed during the day. The energy released is used for the evaporation of water molecules in the night hours to increase the evaporation during the night.

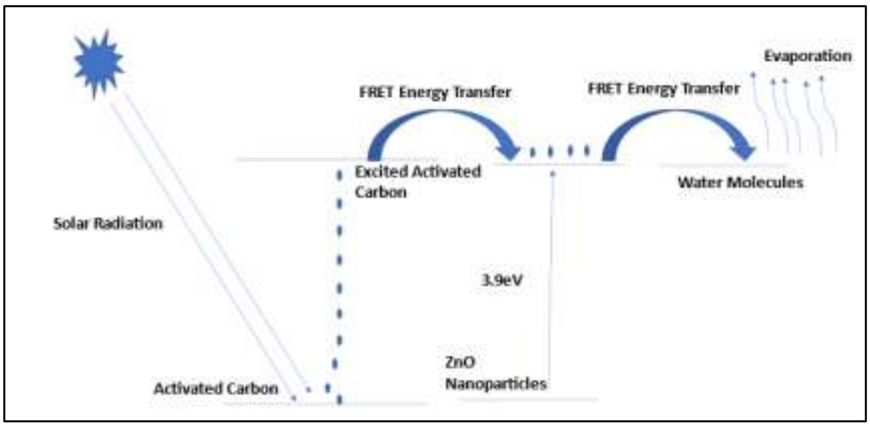

Figure 14.9: Schematic Representation of FRET Mechanism

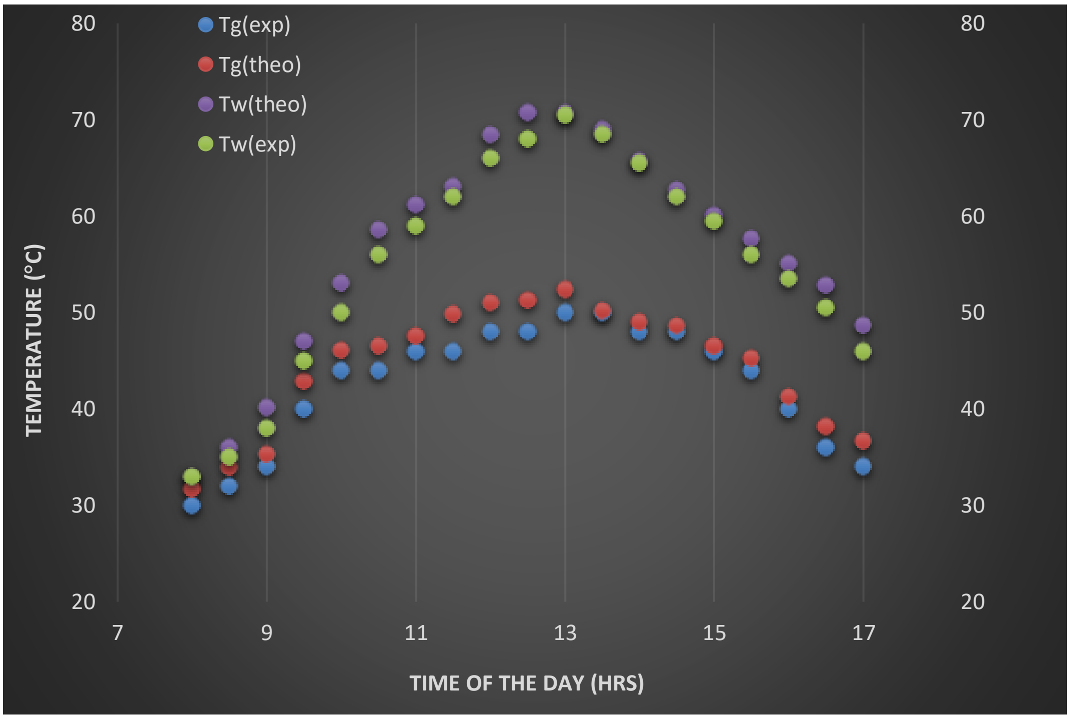

Figure 14.10: Theoretical and Experimental Temperature of Glass Cover and Water

The analytical solution for the glass cover and water temperature in floating and tilted wick surface is found and compared with the experimental observations and represented in Figure 14.9.

It is observed that both the theoretical and experimental observation has conjoint trend with least error which clearly reflects the suitability of the equation for simulation work for still for the location with similar climatic conditions.

The equation governing the FRET mechanism can be written as

$$E_{adsactC} + E_{absZnO} = E_{transW} \quad (26)$$

The Energy received by the water molecule is utilized for the evaporation process and seems to be faster than the still without ZnO/Activated Carbon. The evaporative heat transfer is found for the still with and without the nanocomposite and depicted in Figure 14.10.

From the figure, it is seen that the evaporative heat transfer from the still with nanocomposite is pronounced throughout the working day of the hour.

This is due to the fact that, the energy is transferred to the water molecules in the tilted and floating wick surface by FRET mechanism which is additional energy due to the presence of ZnO/Activated carbon in addition to the energy absorbed directly by the water molecules. This is in turn increases the rate of evaporation from the still with the nanocomposites.

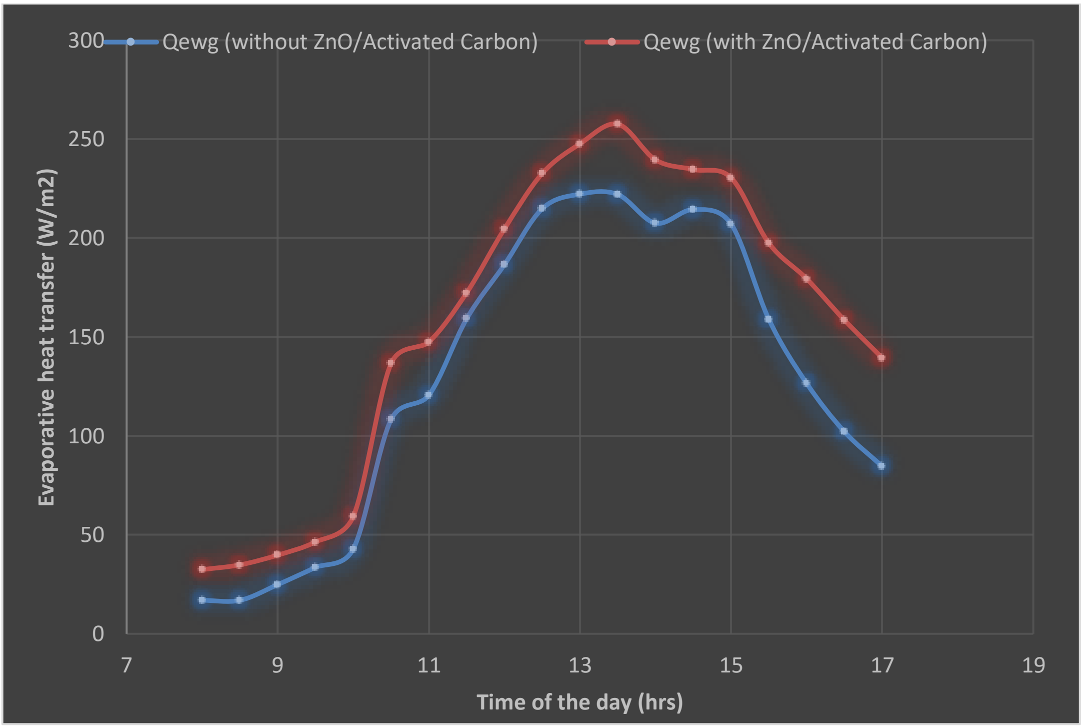

Figure 14.11: Evaporative Heat Transfer for The Still with and Without Nanocomposite

Followed, the instantaneous distillate yield and efficiency obtained for the still with and without nanocomposite has been found and depicted in Figure 14.11.

From the observation, it is found that the maximum distillate yield is obtained at 13.00 and 13.5 hours of about 0.358 and 0.335 kg/m^2 30 minutes which is higher than the still without nanocomposite.

The daily total distillate yield of 5.123 l/m^{2}day over 24 hr cycle out of which 1 liter of distillate yield is obtained during nighttime.

The nighttime output is due to the thermal energy released by the phase change material of paraffin during its phase change.

The daily average efficiency of 42.53% is obtained for the solar still with ZnO/Activated carbon with paraffin wax.

The FRET mechanism is thoroughly undergone inside the solar still and influences the evaporative heat transfer due to the energy transfer from activated carbon to ZnO nanoparticles and then to the water molecules.

The corrugated wick surface on the water tank has significant impact on the reduction of impurities during the initial process of evaporation from the wick surface.

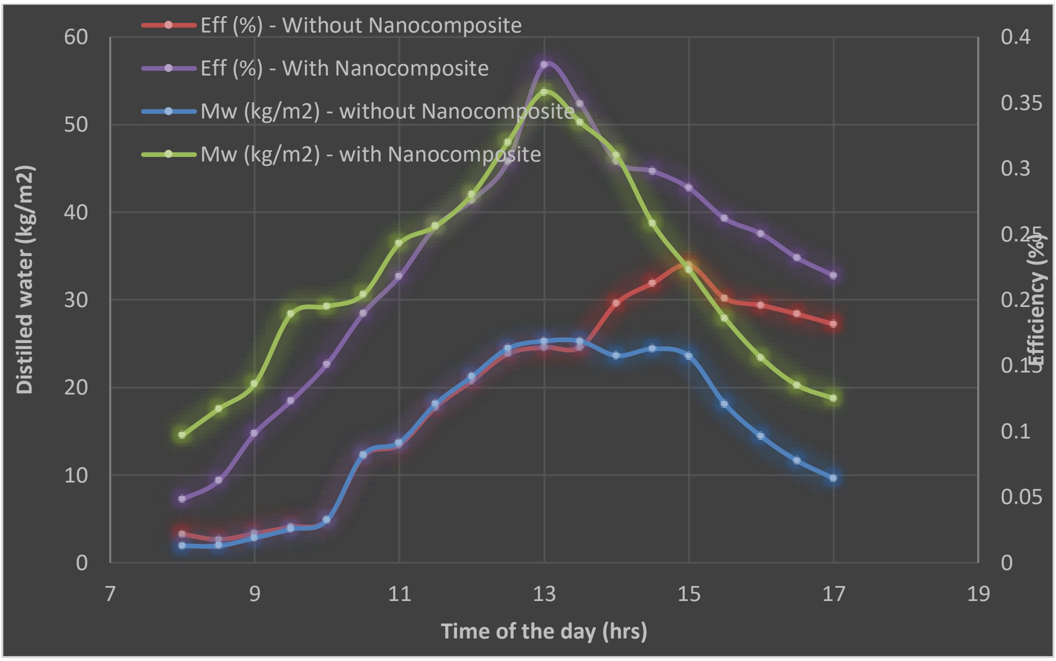

Figure 14.12: Instantaneous Distillate Yield and Efficiency with And Without Nanocomposite

14.4 Conclusions:

The proposed solar still with ZnO/Activated carbon and paraffin wax has increased the amount of distillate yield and efficiency of about 5.123 l/m^2day and 42.53%. The energy transfer by FRET mechanism is evidently proved by evaluating the evaporative heat transfer, instantaneous distillate yield and efficiency which is higher than the still without the nanocomposite and paraffin wax. It is also observed that the synthesis of activated carbon from arecanut shell and utilization of commercially available ZnO nanoparticles along with the paraffin wax has greatly enhanced the amount of energy required for the evaporation process. Moreover, the FRET mechanism is a collision free process which enhances the energy transfer without disturbing the confinement of the water molecules within the range of evaporation temperature rapidly.

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