Quest Journals
Journal of Research in Mechanical Engineering
Volume 10 ~ Issue 4 (2024) pp: 34-44
ISSN(Online):2321-8185
www.questjournals.org

Research Paper

An Experimental Study of the Effect of Some Design Factors of Flat Solar Collectors on Performance

Mujahed Kareem Oglah[1*], Hussein Sabah hashim[2]
*1*Department of Mechanical Technologies- Samawah Technical Institute- Al-Furat Al-Awsat Technical University, Iraq.*
2Department of Oil and Gas Technologies- Samawah Technical Institute- Al-Furat Al-Awsat Technical University, Iraq.

Abstract
This research dealt with an experimental study on the effect of adding radiation-reflecting materials (mirrors, cellophane) on the performance of the complex. Reflective materials were added to the longitudinal sides of the flat solar collector (plate, tube), and three collectors were manufactured with the same dimensions and installed in the same place and subject to the same weather conditions, so that the flow of the working fluid is equal among them, as follows:

- *Ordinary flat solar collector*
- *A flat solar collector whose inner longitudinal sides are coated with cellophane*
- *A flat solar collector whose longitudinal sides are equipped with reflective mirrors*

The research included an experimental study on the collectors that were designed and manufactured (regular, equipped with mirrors, and equipped with cellophane). This study includes measuring the intensity of solar radiation, the temperature of the surrounding environment, and both the temperature of entry and exit of the fluid from the collectors in the case of a constant flow of the operating fluid, at the installation site. The three complexes are on the roof of one building. In addition, testing the performance of flat solar collectors of regular design equipped with mirrors and equipped with cellophane.
Keywords: Keywords: flat solar collector, reflective mirrors, reflectors (mirrors, cellophane); The yield of the solar collector.

Received 11 Aug., 2024; Revised 25 Aug., 2024; Accepted 27 Aug., 2024 © The author(s) 2024. Published with open access at ***www.questjournals.org***

I. Introduction

The importance of research studying flat solar collectors stems from the fact that it is one of the basic technologies in converting solar energy into thermal energy, to be used in many thermal applications.

Therefore, it concerns the development of one of the important technologies in exploiting solar energy, which in turn is the most important source among renewable energies.

These researches are concerned with either reducing the cost of the solar collector, or reducing thermal losses from the collector.[1]

Studies that dealt with reducing thermal losses from the collector focused on how to insulate the collector box, and add special coverings to the surface of the absorbent plate (selective surfaces) to reduce its emissivity of thermal rays without reducing its absorption, or using a system of multiple covers to reduce heat losses due to convection and radiation. Alternatively, adding transparent insulating materials between the cover and the absorbent plate, or emptying the space between the cover and the plate to prevent load losses from occurring, or providing the covers with radiation-reflecting materials to increase the permeability of the covers system to solar rays. [2]

After the solar rays pass through the cover system, the solar rays reach the absorbing plate. The plate absorbs a large portion of the radiation according to its absorption property, but some of these rays are reflected from the plate on the internal sides of the collector and the cover.

Then these rays bounce back to the plate according to the ability to reflect the radiation on those surfaces. The plate again absorbs part of the radiation and the other part bounces back on the sides entering the collector and the cover. Thus, the reflections multiply and the plate’s absorption of radiation increases as the rays reflected on it increase.

Therefore, providing the internal sides of the flat solar collector, especially its longitudinal sides, with smooth materials that have a high ability to reflect rays can increase the rate of absorption of radiation by the plate and thus reduce heat losses to the surrounding environment. Therefore, attention was paid in this research experimentally to study the effect of adding materials with good reflectivity (mirrors, cellophane) to the longitudinal internal sides of the flat solar collector on the thermal losses resulting from radiation reflection and its effect on increasing the yield.

Naghavi et al. 2017 [3] designed a compact solar water heater with latent heat storage, and experimental testing was performed for different flow rates and weather conditions.

Researchers conducted an experimental investigation on the design of a solar water heater (SWH) system using vacuum heat tube solar collectors (HPSCs) and a latent heat storage (LHS) tank

Naghavi et al collected solar energy on the HPSC and stored it in the LHS tank via a heat pipe with fins connected to the ends of the condenser inside the LHS tank. The stored heat is then transferred to the water supply via a set of finned tubes located inside the LHS tank.

Naghavi et al. presented the design, working principles, and experimental thermal processes for charge and discharge modes only, as well as the effects of weather conditions in a tropical region, water flow rates, and hot water withdrawal time.

The researchers reached the following results: [4, 5, 6]

- The proposed system is a stable system under different conditions.
- System efficiency on sunny days is 38-42% while on cloudy and rainy days it is 34-36%.
- The problem of stratification is removed by the new latent heat storage tank.
- The thermal efficiency of the system on sunny days ranges between 38%-42%, while on cloudy days this efficiency drops to a range of 34%-36%, indicating a fluctuation range of about 8% under different conditions.
- The flow rate has a direct proportion on the overall efficiency of the system in the range tested.
- The advantages of heat pipe and phase change materials together cover their disadvantages such as high temperature of heat pipe and low thermal conductivity of phase change material.

Researchers Alexios et al. 2016 [7] studied a new method for incorporating phase change materials (PCMs) inside vacuum tube solar collectors for solar water heaters (SWHs).

They immersed the heat pipe inside a phase change material, where heat is effectively collected and stored for a long period of time due to the thermal insulation of the evacuated tubes, in order to improve functionality by delaying the release of heat, thus providing hot water during hours of high demand or when the density is high. Solar energy is not enough.

Work's Objectives:

The percentage of losses resulting from the reflection of solar rays from the cover and the absorbing plate constitutes about 16% of the radiation falling on the complex, as part of it is reflected from the cover, and the other part is reflected from the absorbing plate. This research paid attention to reducing this percentage of losses because of its It has the effect of increasing the yield of the complex and improving its performance.

Experimental Setup:

To compare the thermal performance of collectors with a modified design (coating the inner sides of the collector with mirrors or cellophane) with a collector with a regular design, three collectors were manufactured with the same dimensions and specifications and do not differ from each other except that:

- The first one has a normal design.
- The second is a complex equipped with reflective mirrors 8cm high on both sides.
- The third is an assembly whose inner sides are covered with cellophane at a height of 8cm.

The dimensions of each complex are shown in Figure 1 and Table 1:

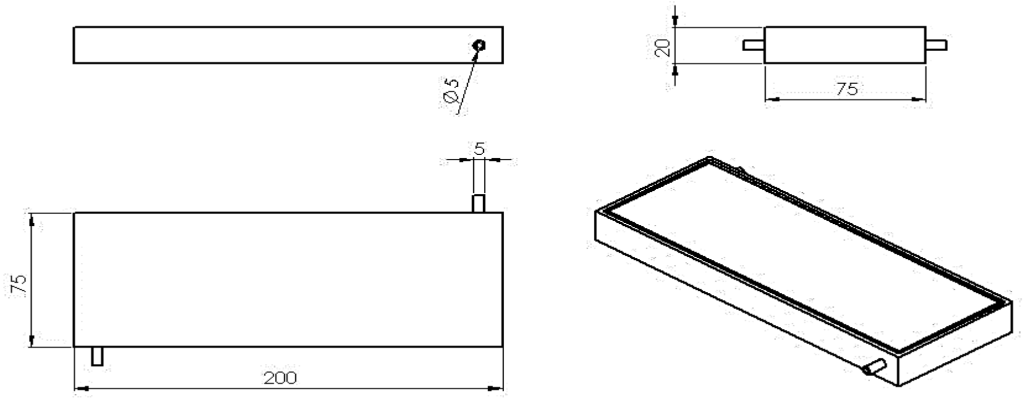

Figure1:Projections of the solar complex

Table 1:

Latitude angle of the complex location	$\emptyset = 35.20^{\circ}$	
Inclination tendency	$\beta = 45^{\circ}$	
Length	$L_{coll} = 1.76m$	the complex
Width	$W_{coll} = 0.76m$	
thickness	$\delta_{coll} = 0.18m$	
Length of the absorbent plate	$L_p = 1.7m$	the absorbent plate
Width of the absorbent plate	$W_p = 0.75m$	

$N = 1$	Number of covers	the cover
glass	Materiel	
Permeability	$\tau_g = 0.87$	
Emissivity	$\varepsilon_g = 0.88$	
The space between the plate and the cover	h=0.11m	

Subject	Red brass plated with matte black paint	The plate
Thermal conductivity	$k_p = 385 \frac{w}{m.℃}$	
Thickness	$\delta_p = 0.0005m$	
Absorbency	$\alpha_p = 0.98$	
Emissivity	$\varepsilon_p = 0.98$	

Thickness	$\delta_e = 0.05m$	Black insulators
Thermal conductivity	$k_e = 0.045 \frac{w}{m.℃}$	
Thickness	$\delta_b = 0.05m$	Side insulators

Thermal conductivity	$k_b = 0.045 \frac{w}{m.℃}$	

Number of tubes	9	Pipes and liquid
Inner diameter	$D = 0.01m$	
Thermal conductivity of the connection area between the tube and the plate		
Operating mediator	water	
Total mass flow	$\dot{m} = 0.00598 \frac{kg}{s}$	
Specific heat	$c_p = 418 \frac{j}{kg\ k}$	Pipes and liquid
Density	$\rho = 998.2 \frac{j}{kg\ k}$	
Viscosity	$\mu = 1.006 . 10^{-6} \frac{kg}{sec.m}$	
The speed of fluid flow in the tube	$\dot{v} = 0.00847 \frac{m}{sec}$	
T Thermal conductivity of water	$k_f = 0.597. 10^{-3} \frac{w}{m.k}$	

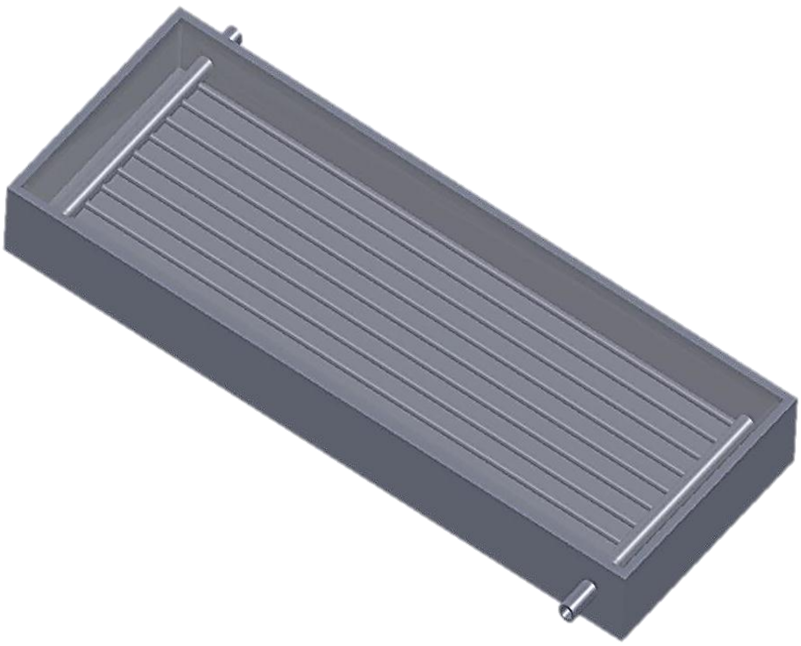

Figure2: Normal design of flat solar collector


Figure3: The three solar collectors at their installation site

The three collectors were installed in parallel on a building roof that would not be exposed to shading throughout the period of solar brightness. The inclination of the collectors was chosen at an inclination angle of =45○β. The three collectors were facing south and exposed to the same weather conditions with a constant flow of working fluid for each collector.
The intensity of solar radiation at the collector level was measured using a pyrometer (Global Water's WE300 Solar Radiation Sensor) [8]
The ambient temperature was measured using a thermometer placed in the shade of the complexes at the back, facing north. In addition to measuring the temperature of the fluid entering and exiting the accumulator:
I_{Gt}: The intensity of solar radiation falling on the collector level, measured as w/m^2
Tf,i: The temperature of water entering the collectors, measured in C°
$T_{f,o}$: The temperature at which water leaves the ordinary accumulator, measured in C°
$T_{f,om}$: The temperature at which water exits the mirrored collector and is measured in C°
$T_{f,os}$: The temperature at which water exits the cellophane collector, measured as C°
T_a: The temperature of the ambient air, measured in C°.
Each of the previous parameters of each complex is entered into a database, these values are processed, and thermal calculations are generated (the amount of useful heat and the yield per hour of each day, for each day separately, and in the month studied).

Governing equations:

Useful amount of heat from the relationship: [9]

$$Q_U = \dot{m}c_p(T_{f,o} - T_{f,i}) \quad 1$$

The yield, which is the ratio between the useful energy gains during a specific period to the incident radiation in the same period of time, is calculated from the relationship:

$$\eta = \frac{Q_u}{A_c I_{Gt}} = \frac{\dot{m}c_p(T_{f,o} - T_{f,i})}{A_c I_{Gt}} \quad 2$$

When comparing the performance of complexes in terms of yield, reliance is placed on the previous yield relationship in drawing graphs because all values in the previous equation are experimentally measured values.
It is also used in calculating the return relationship:

$$\eta = EFT_2 = F_R\left[(\tau_G \alpha_P) - U_L(T_{f,i} - T_a)/I_{Gt})\right] \quad 3$$

Where: U; The total loss factor is the sum of the upper and lower losses and the losses on the edges.
The heat transfer factor by convection within the pipe is given in terms of the Nusselt number by:

$$h_{f,i} = \frac{Nuk_f}{D_i} \quad 4$$

For turbulent flow for fluids whose Prandtl number is between 1 → 20, Nusselt is given by the relationship [9]:

$$Nu = 0.0155\,\mathrm{Re}^{0.83}\,pr^{0.5} \qquad 5$$

The thermal resistance between the plate and the liquid is given by the following relationship:

$$R_{p,f} = \frac{1}{h_{f,i}\pi D_i n l} \qquad 6$$

$$F_R = \frac{\dot{m}c_p}{A_c u_l}\left[1 - \exp\left(\frac{A_c u_l F'}{\dot{m}c_p}\right)\right] \qquad 7$$

Where Ac: the effective area and is related to the number of tubes and the length of the tube and is given by:

$$A_c = nWL \qquad 8$$

The collector yield factor represents the temperature distribution along the absorbent plate between the tubes and is calculated by the following relationship:

$$F' = \frac{1/u_l}{W\left[\dfrac{1}{u_l\left[D + (W - D)F\right]} + \dfrac{1}{\pi D_i h_{f,i}}\right]} \qquad 9$$

$$F = \frac{\tanh m(W - D)/2}{m(W - D)/2} \qquad 10$$

$$M = \sqrt{\frac{U_l}{k\delta}} \qquad 11$$

The return is also calculated from the relationship

$$\eta = EFT = F'\left[(\tau_G \alpha_P) - U_L (T_{fm} - T_a)/I_{Gt})\right] \qquad 12$$

$$T_{fm} \approx \frac{(T_{f,o} + T_{f,i})}{2} \qquad 13$$

II. Results:

Table 2: Total useful heat for the three complexes between 29/4/2024 and 29/5/2024

cellophane collector∑ QUS(w)	**the mirrored collector ∑QUM(w)**	**accumulator yield QU(w)∑**
62638 w	68831 w	60075 w

Table 3: Returns over the period studied in the test for the three complexes between 29/4/2024 and 29/5/2024

Yield of cellophane collector ηS(w)	**The yield of the mirrored collector ηM(w)**	**Normal accumulator yield η(w)**
0.4490	0.4536	0.43

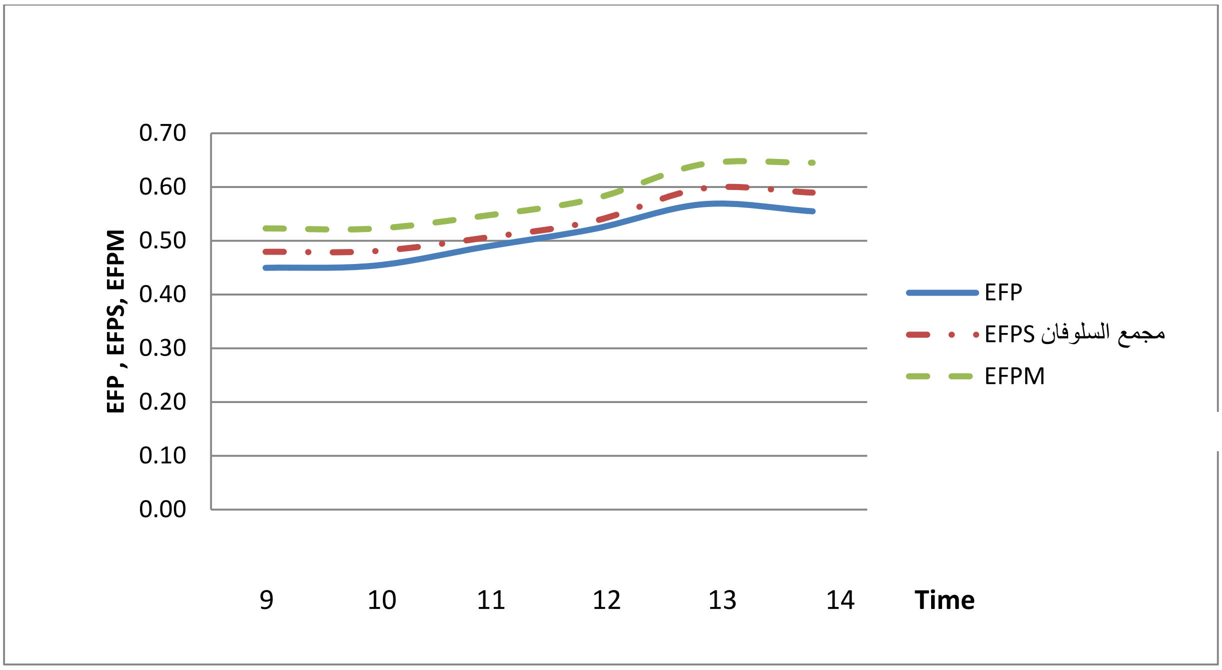

Figure 4: The yield of the three complexes on a clear day 29/4/2024 as a function of the hours of the day. EFP: Ordinary flat solar collector, **EFPS:** A flat solar collector with cellophane**, EFPM:** A flat solar collector with mirrors

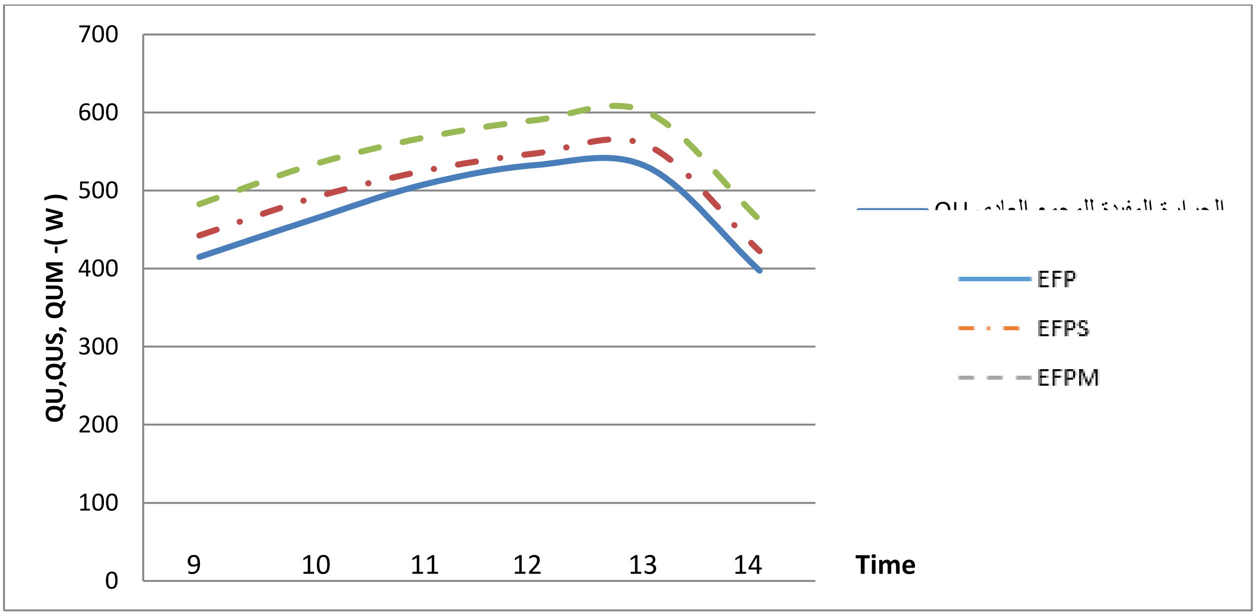

Figure 5: The useful temperature of the three complexes on a clear day 29/4/2024 as a function of the hours of the day. EFP: Ordinary flat solar collector, **EFPS:** A flat solar collector with cellophane**, EFPM:** A flat solar collector with mirrors

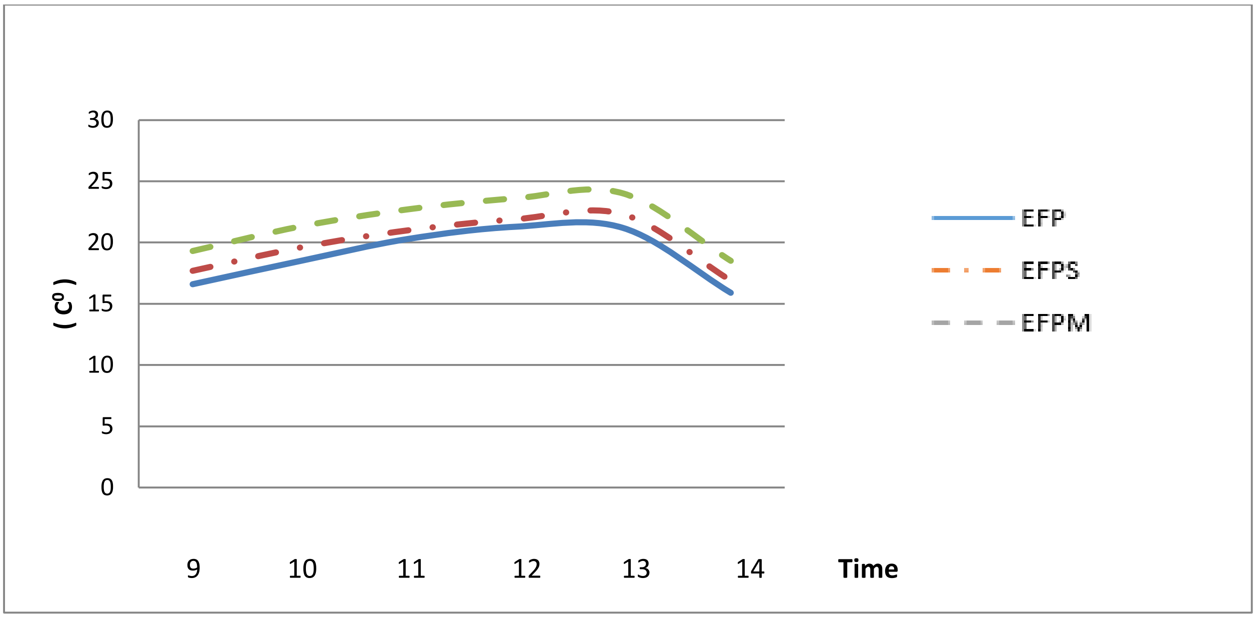

Figure 6: The difference between the inlet and outlet temperatures of the liquid on a clear day 29/4/2024 for the three solar collectors as a function of the hours of the day. EFP: Ordinary flat solar collector, **EFPS:** A flat solar collector with cellophane**, EFPM:** A flat solar collector with mirrors

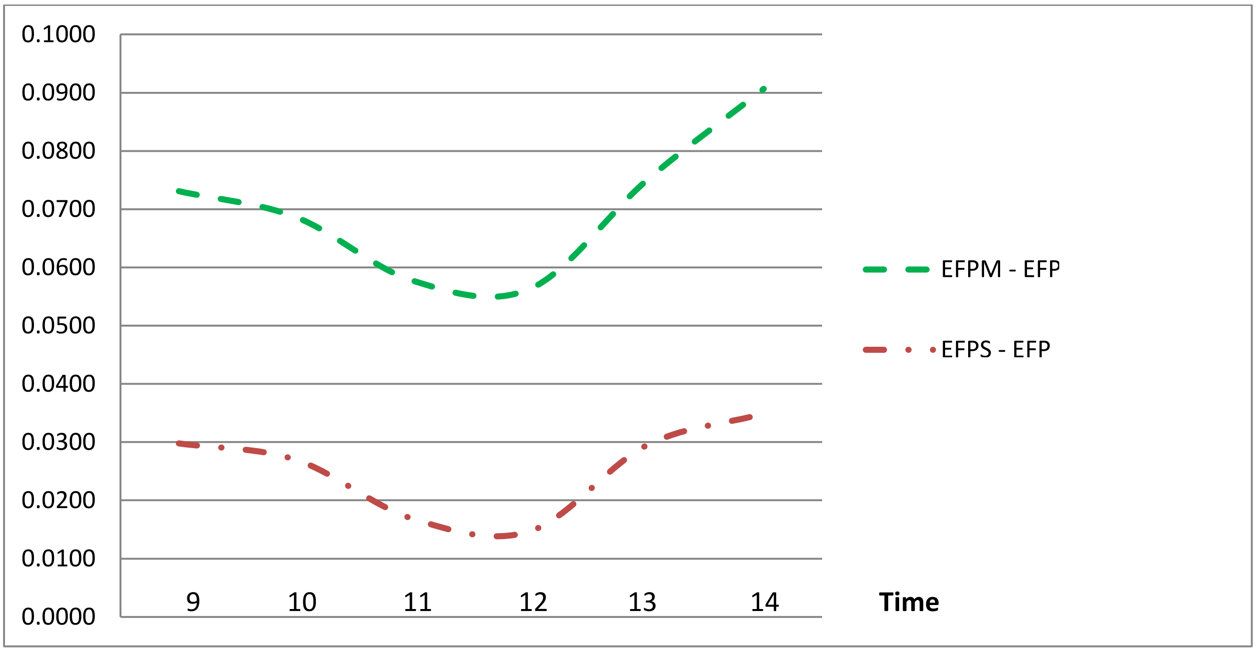

Figure 7: The difference in efficiency between the mirrored collector and the regular collector and between the cellophane collector and the ordinary collector on a clear day as a function of the hours of the day

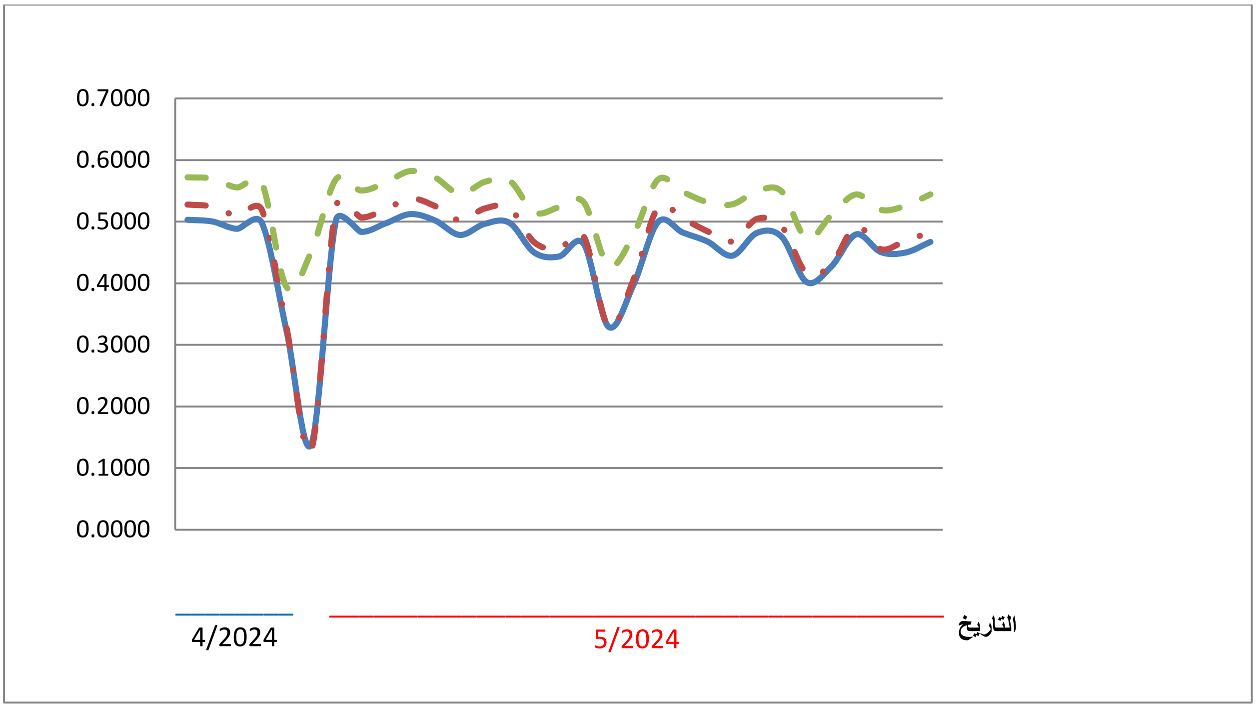

Figure 8: Yield of the three complexes over 31 days

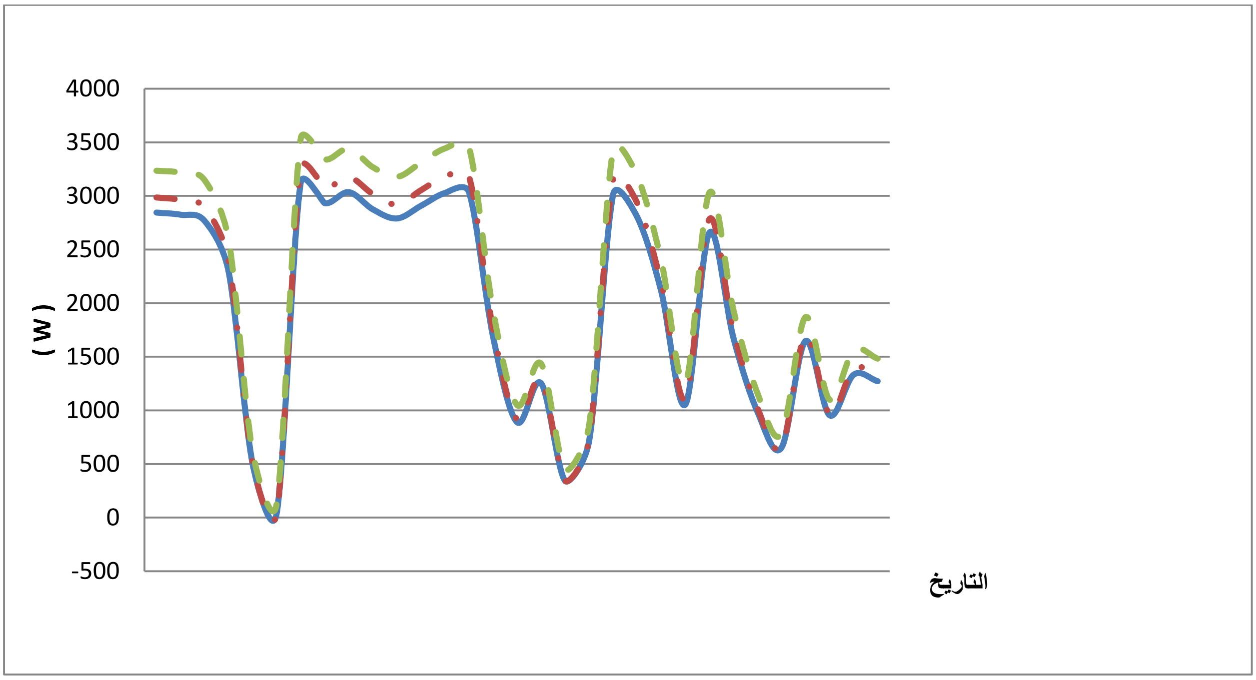

Figure 9: Useful heat for the three complexes over 31 days

III. Conclusions

Figure 4 shows the yield of the three solar collectors as a function of hourly time on a clear day 29/4/2024:

• The performance of the two collectors was compared with the performance of a regular complex in terms of yield. Moreover, the results taken over the course of a month - from 29/4/2024 to 29/5/2024 - showed that the yield of the complex equipped with mirrors is the best. m = 0.453, and the complex equipped with cellophane shows an improvement in yield. For the ordinary collector, s = 0.449, while the yield of the ordinary collector, s = 0.43, meaning that the value of the difference in the yield between the collector equipped with mirrors.

• The ordinary collector is m-η = 0.0229, and the difference in the value of the yield between the collector equipped with cellophane and the ordinary collector is s-η = 0.0184, the difference in the value of the yield between the complex equipped with mirrors and the one equipped with cellophane is m-s = 0.0046.

- The yield of each of the collectors until noon does not show a noticeable increase. This is due to the inertia of the collector, as the collector consumes at the beginning of its operation an amount of intense solar radiation to heat the collector mass. At noon and until one o'clock in the afternoon, the value of the yield in each collector increases. The percentage of thermal gain is greater than the percentage of losses because the amount of solar radiation increases and the air temperature Ta increases, so the percentage of thermal losses decreases due to the decrease in the difference between the temperature of the plate Tp and the temperature of the surrounding medium Ta.
- The collector equipped with mirrors shows an improvement in yield by approximately 2.7% over the yield of the regular collector, as the amount of radiation absorbed by the plate has increased resulting from increased reflection of radiation to the surface of the absorbing plate due to the presence of mirrors on the longitudinal internal sides of the collector.

The collector equipped with cellophane shows an improvement in yield by approximately 2.2% over that of the regular collector, as the amount of radiation absorbed by the plate increased because of the increased reflection of radiation to the surface of the absorbing plate due to the cellophane coating the longitudinal inner sides of the collector

The collector equipped with mirrors shows an improvement in yield by approximately 0.47% over the yield of the collector with cellophane.

as the amount of reflections from the sides equipped with mirrors is greater than the sides equipped with cellophane due to the value of the reflective property of the mirrors, ρm=0.96, being greater than that of the cellophane, ρs=0.76.

From Figure 7, which represents the difference in yield between the mirrored collector and the regular M-η collector, and the difference in yield between the cellophane collector and the regular S-η collector on a clear day 29/4/2024, we note:

- The lowest value of the m-η difference and the s-η difference occurs in the afternoon, when from 11 o'clock until 12 noon the difference for m-η decreases up to 5.5%, and for s-η up to 1.3%. In the period before noon, the percentage difference for m-η reaches about 7.3%, while for s-η it reaches about 3%.

The lower value of the difference in yield in the two collectors with mirrors and cellophane compared to the regular collector in the afternoon; is due to the angle of incidence of radiation, which is close to the angle 90○.

Nevertheless, it is not exactly equal to it, as if the angle of incidence were perpendicular to the surface of the plate; the angle of reflection of the radiation would be parallel to the surface of the plate.

Since the plate benefited from reflection, and this only happens when the sun is traced by changing the direction and inclination of the collector, the collector maintains an angle of incidence of solar radiation completely perpendicular to the plane of the absorption surface. In the period before noon and afternoon, the angle of incidence of radiation is inclined, so a larger area of reflective surfaces contributes to the reflection of radiation to the surface of the plate.

- From Figure 8, which represents the yield of the three complexes over 31 days, we note:
- The mirrored collector shows an improvement in efficiency over the yield of the regular collector.
- The cellophane collector throughout the days of the month - clear and partly cloudy days - but it shows a greater percentage of improvement on partly cloudy days as it appears that part of the spread radiation falls on the reflective surfaces - the mirrors - To be reflected on the surface of the absorbing plate.
- The amount of radiation absorbed by the plate increases with the presence of radiation-reflecting surfaces - mirrors - installed on the longitudinal internal sides.

As for the collector equipped with cellophane, it shows an improvement in the return value throughout the days of the month.

- However, it shows a lesser improvement on cloudy days, as the percentage of reflection of the spread radiation on the longitudinal internal sides of the collector with cellophane on cloudy days is small, so the complex does not benefit clearly from the spread radiation as in Mirror complex because the value of s is small compared to m.
- The return value over the course of the month from 29/4/2024 until 29/5/2024 for each of the three complexes we note:
- The return value of the collector equipped with mirrors is the best during the test month on clear and partly cloudy days, as the difference in the return value between the collector equipped with mirrors and the regular collector is: m-η = 0.0229.
- The compound supplied with cellophane shows an improvement in yield over the regular compound, as the difference between the two yields is: s-η=0.0184.
- The collector equipped with mirrors shows an improvement in yields over the collector equipped with cellophane, as the value of the difference between the two yields is: m-s = 0.0046.We recommend adding mirrors on the longitudinal inner sides of the flat solar collector.

References:

[1]. A. E. Kabeel, Mohamed M. Khairat Dawood, Tamer Nabil, Bader essaelnoafal, “Performance improvement of stepped solar still using PCM with internal reflectors integrated with an evacuated tube solar water collector”,2019.

[2]. K. Chopra, V.V. Tyagi, A.K. Pandey, Ravi Kumar Sharma, Ahmet Sari, “PCM integrated glass in glass tube solar collector for low and medium temperature applications: Thermodynamic & techno-economic approach”, 2020.

[3]. Chopra, Atin K. Pathak, V.V. Tyagi, A.K. Pandey, Sanjeev Anand, Ahmet Sari, "Thermal performance of phase change material integrated heat pipe evacuated tube solar collector system": An experimental assessment, 2020

[4]. Vivek R. Pawar, SarvenazSobhansarbandi, “CFD modeling of a thermal energy storage based heat pipe evacuated tube solar collector", 2020.

[5]. A. D. Rincon-Quintero, W. L. Rondon-Romero, O. A. Acosta-Cardenas, (2022). “Experimental Study of a Flat Solar Collector with Thermal Energy Storage, Applying Improvements Based on Bibliometric Review and CAD Simulation”, Applied Technologies

[6]. Abu Shadate Faisal Mahamude, Wan Sharuzi Wan Harun,KumaranKadirgama ,Devarajan Ramasamy,KanizFarhana,Khalid Saleh andTalalYusaf, (2022). “Experimental Study on the Efficiency Improvement of Flat Plate Solar Collectors Using Hybrid Nanofluids Graphene/Waste Cotton”.

[7]. M. Esapour, M.J. Hosseini, A.A. Ranjbar , Y. Pahamli, R. Bahrampoury, “Phase change in multi-tube heat exchangers”, 2016

[8]. Essam M. Abo-Zahhad, Shinichi Ookawara , Ali Radwan , A.H. El-Shazly, M.F. Elkady, “Numerical analyses of hybrid jet impingement/microchannel cooling device for thermal management of high concentrator triple-junction solar cell”, 2019.

[9]. Alireza Hobbi , Kamran Siddiqui, (2009). “Experimental study on the effect of heat transfer enhancement devices in flat-plate solar collectors”, International Journal of Heat and Mass Transfer.