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Transforming Traditional Photovoltaic Panels into Thermal/ Photovoltaic Panels Incorporating Composite-Phase Change Materials

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Abstract

Solar panels are constantly evolving, with changes occurring in the materials used, panel shapes, and the method used to attach solar cells to the panels. Solar radiation consists of two components: photovoltaic energy, which is used to generate electricity via photovoltaic panels, and thermal energy, which, on the other hand, can reduce the efficiency of photovoltaic panels. Thermal photovoltaic panels are a recent breakthrough in the industry as they use light to generate energy and heat to reheat cryogenic liquid for a variety of purposes. One subtype that is gaining popularity is hybrid photovoltaic thermal panels, which are designed to enhance heat use by adding a heat storage medium, with phase change materials being a noteworthy example. Despite their numerous benefits, these materials have limited heat conductivity, necessitating substantial research efforts to improve this attribute. However, most research focus solely on enhancing conductivity without applying the findings to PV panels in a comprehensive manner. This study fills this gap by reviewing the phase change materials accessible locally, picking Iraqi wax, researching additions, selecting micro- particles of aluminum oxide (Al_2O_3), investigating the mixing procedure, and calculating the ideal mixing ratio (6% additive to wax). The combination is then placed to a normal solar panel, resulting in a hybrid photovoltaic panel with a complicated phase transition material reinforced with aluminum oxide.

Keywords: Phase Change Materials, PV/T, Iraqi wax, Al_2O_3, Hybrid PV/T.

تحويل الألواح الكهروضوئية التقليدية إلى ألواح كهروضوئية حرارية تحتوي على مواد متغيرة الطور- مركبة.

مصطفى خالد احمد، عبد الجبار نعمة خليفة

الخلاصة:

تتطور الألواح الشمسية باستمرار، مع حدوث تغييرات في المواد المستخدمة في انتاج الالواح الكهروضوئية وأشكال الألواح والطريقة المستخدمة لربط الخلايا الشمسية داخل الألواح. يتكون الإشعاع الشمسي من عنصرين: الطاقة الضوئية، والتي تستخدم لتوليد الكهرباء عبر الألواح الكهروضوئية، والطاقة الحرارية، والتي من ناحية أخرى، يمكن أن تقلل من كفاءة الألواح الكهروضوئية. تعد الألواح الكهروضوئية الحرارية إنجازًا حديثًا في هذه الصناعة حيث تستخدم الضوء لتوليد الطاقة والحرارة لإعادة تسخين السائل المبرد لمجموعة متنوعة من الأغراض. أحد الأنواع الفرعية التي تكتسب شعبية هي الألواح الحرارية الكهروضوئية الهجينة، والتي تم تصميمها لتعزيز استخدام الحرارة عن طريق إضافة وسيلة تخزين الحرارة، مع كون المواد المتغيرة الطور مثالًا جديرًا بالملاحظة على الرغم من فوائدها العديدة، فإن هذه المواد لديها موصلية حرارية محدودة، مما يستلزم بذل جهود بحثية كبيرة لتحسين هذه الخاصية. ومع ذلك، تركز معظم الأبحاث فقط على تعزيز الموصلية دون تطبيق النتائج على الألواح الكهروضوئية بطريقة شاملة. تسد هذه الدراسة هذه الفجوة من خلال مراجعة المواد المتغيرة الطور المتوفرة محليا،

واختيار الشمع العراقي، والبحث عن الإضافات، واختيار جزيئات صغيرة من أكسيد الألومنيوم، ودراسة عملية الخلط، وحساب نسبة الخلط المثالية (٦٪ من لمادة المضافة إلى الشمع). يتم بعد ذلك وضع المزيج على لوحة شمسية عادية، مما ينتج عنه لوحة كهروضوئية هجينة مع مادة متغيرة الطور معقدة معززة بأكسيد الألومنيوم.

1. Introduction

Researchers worldwide have made energy development and exploration of various energy sources their primary focus. Clean and unlimited energy sources, especially those beyond fossil fuels, are being extensively studied as potential major contributors to the global energy landscape [1].

In the pursuit of harnessing solar energy, solar panel manufacturers are actively working on developing photovoltaic panels to convert the sun's radiant energy into usable electrical power for diverse applications. However, these solar panels encounter challenges, and one critical issue is the impact of high temperatures. During the photovoltaic process, some solar energy is converted into unwanted heat, leading to a rise in the temperature of the panels and subsequently reducing their electrical conversion efficiency. For example, crystalline and amorphous silicon cells experience a decline in electrical efficiency of 0.5% and 0.25% per degree Celsius of temperature increase, respectively [2].

To address this problem, researchers have explored alternative solutions such as thermal photovoltaic (PV/T) panel systems, aiming to utilize the heat generated through thermal PV modules. However, the effectiveness of these systems has been limited due to their reliance on heat transfer media with restricted thermal conductivity.

In response, the researchers developed an advanced PV/T system by incorporating Phase Changing Materials as efficient heat transfer media between the back surface of the panel and the coolant-carrying pipes.

Numerous phase-changing materials were evaluated, each having its strengths and weaknesses. The focus of the research was to identify a heat transfer medium with high latent heat and good conductivity, resulting in improved power output from the solar panels and optimized temperatures on both the top and bottom surfaces of the solar panel. Additionally, efforts were made to increase the temperatures of the coolant as it exits the system, contributing to overall system efficiency and performance.

2. The PV panel

A solar panel, also referred to as a photovoltaic panel, is a device that uses the photovoltaic effect to convert sunlight into electrical energy. It serves as a vital component in solar energy systems, and contributes significantly to clean, renewable energy generation.

Table (**1**) presents the details and specifications of the solar panel used in this study, which will be subject to many changes to be converted from a PV panel to a PV / T panel with the introduction of the necessary changes to add the PCM in order to improve the thermal and electrical performance of the panel.

3. The PV/T panel

A PV/T panel, also known as a photovoltaic/thermal panel or hybrid solar panel, is a device that combines both photovoltaic and solar thermal technologies in a single unit. It allows for the simultaneous production of electricity and heat from solar energy, making it a more efficient and versatile system.

In a PV/T panel, the photovoltaic component converts sunlight into electricity, similar to a traditional solar panel. At the same time, the thermal component captures heat from the sunlight and transfers it to a fluid or air, which can be utilized for various heating purposes or even electricity generation through thermal processes. The PV/T panel offers many advantages over standalone solar PV systems. It increases the use of solar energy by capturing both electrical and thermal energy simultaneously. This integrated design also reduces the total area required for installation, making it suitable for areas with limited space. In addition, the combined system improves overall efficiency by taking advantage of excess heat generated by the photovoltaic cells, which can enhance the performance of the solar cells themselves.

In this study, a cooling system comprising a copper tube is installed behind the photovoltaic panel. The specifications and characteristics of this copper tube are given in Table (2), while Figure (1) shows the shape of the tube at the backside of the solar panel. Water is used as a cooling medium and flows through the copper tube. The addition of this heat transfer system allows the simultaneous production of both electrical energy from the PV panel and thermal energy from excess heat, thus converting the PV panel into a PV/T panel. Table (2) and Figure (1) provide a comprehensive overview of the copper tube details and the configuration of the solar PV/T solar panel respectively.

Table (1) PV panel details

Manufacturer company	Al-Mansoure State Company / Ministry of industry and minerals
Imp	7.44 A
ISC	8.05 A
Pmp	130.6 W
Voc	22.33 V
Vmp	17.56 V
Vm	1000V
S.N.	101303324
Length of penal	148 cm

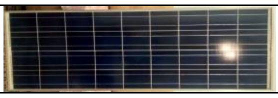
Width of penal	66 cm
Module area	0.9768 m^2
Quality control	A
Product ID	MCM120
Cell serial	36 (9×4)
Cell area	0.023625 m^2
Cell parallel	١
Cell efficiency	15.36%
Module efficiency	13.37%
Slope at ISC	81(Ohm)
Slope at Voc	362(mOhm)
FF	0.727
Current temp. coeff.	10 (micro A/cm^2/°C)
Voltage temp.coeff.	-2.1 (mV/cell/°C)
Series resistance	6 (mOhm/cell)
Curve correction fac.	0.05(mOhm/cell/°C)
Image	
Power measure in standard condition (STC)	

Table (2): Characteristics of the cooling tube used in the system

Cooling tube material	Copper
Made of	South Africa
company	Masksal Tubes
Outer diameter	9.53mm
Wall Thickness	0.81mm
Inner diameter	7.91 mm
length	6.85m
ISO 9001: 2015	

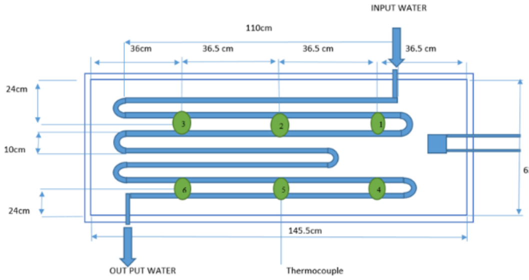


Figure (1): The dimensions of the PV/T panel and the copper tube assembly at the backside of the solar cell with locations of temperature measurement.

4. The Composite Phase Change Material

To enhance the properties of Iraqi paraffin wax, which is used in this study, especially its thermal conductivity, many materials may be combined with the PCM such as nano or micro powders. One such material is Micro-alumina which is used in this study.

4.1. The phase change material used in this work

As mentioned before, the PCM used in this study was that produced by Al-Dura refineries because of its availability and reasonable price. The thermal specifications of this PCM are listed in Table (3). The code between the square brackets indicates the test method.

Table (3): Properties of Iraqi paraffin wax used in this study

Property	**Units**	**value**
Melting point temperature	°C	52
Latent heat of fusion	kJ/kg	193
Thermal conductivity	W/m °C	0.21
Liquid state specific heat	kJ/kg °C	2.1
Solid state specific heat	kJ/kg °C	2.1
Oil percentage	%	2.8
color scale [ASTM D6045]		1.0
Needle Penetration [ASTM D1321]		19
Specific Gravity (Sp. Gr.) [ASTM D-1298]		0.8205
Image		

4.2. Aluminum Oxide characteristics, physical Properties and Structure

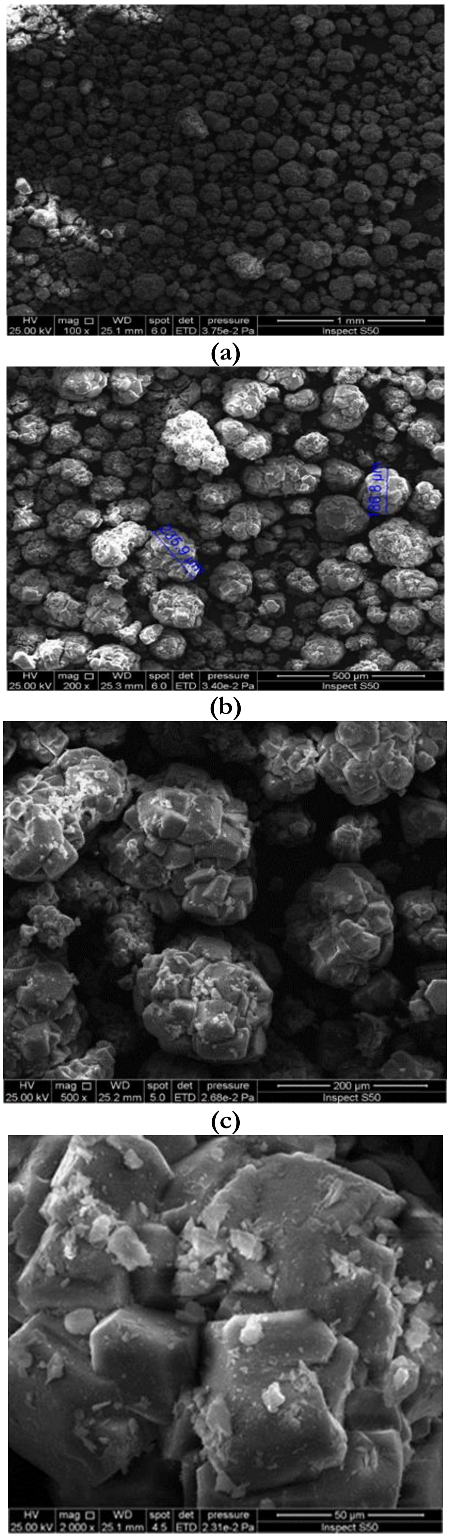
For the purpose of improving the low thermal conductivity of the Iraqi paraffin, Aluminum Oxide (Al_2O_3) is added to enhance the heat transfer between the PCM and the panel and hence improve the efficiency of the PV panel.

Table (4) shows the properties of aluminum oxide used in this study.

Table (4): Characteristics of Al_2O_3

Type	**powder**
Color	white
Made of	England
Chemical formula	Al_2O_3
Supplier	ICN BIOMEDICALS
Origin	Germany
Density	3690 kg/m^3
Specific Heat	880 J/Kg K
Thermal Conductivity	18 W/m K
Purity	95%
Mean diameter Particle	100μm to 240μm
Material	Aluminum oxide

A sample of aluminum oxide (Al_2O_3) was examined using a scanning electron microscope (SEM) [FEI_ Company / Netherlands / Inspect S50 (model)]. The powder particles appeared through the device as shown in Figure (2). It was found that the diameter of the powder particles (Al_2O_3) ranges approximately from 100 to 240 micrometers as shown in Figure (3). It is also clear that the powder atoms are not uniform in size.



(a) (b) (c) (d)

Figure (2): Al_2O_3 powder particles at different magnifications (a) 100X, (b)200X, (c)500X, (d)2000X

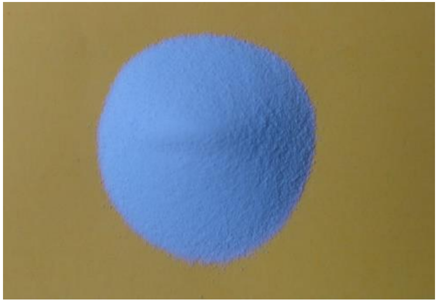


Figure (3): Aluminum Oxide (AL_2O_3) powder

The investigation of (Al_2O_3) purity used in this study was conducted through the application of energy dispersive X-ray spectroscopy (EDX) using [the Bruker Company's XFlash_6l10 model from Germany]. The findings are presented in Table (5), where it is worth noting that two elements (Au and Pt) were intentionally introduced into the material during the examination process. Subsequently, in Table (6), carbon was removed from the sample and through examination it became clear to us that the percentage of purity of the powder is (95.33805%).

Table (5): Results of laboratory test of a powder (Al_2O_3)

Element	symbols	[norm. wt.%]
Aluminum	Al	65.93058
Carbon	C	20.46812
Oxygen	O	7.466893
Platinum	Pt	2.507398
Nitrogen	N	2.461829
Gold	Au	1.165176
Total		100

Table (6): Results of laboratory test of a powder (Al_2O_3) without carbon

Element	symbols	norm. C [wt.%]	Compound	[wt.%]
Aluminum	Al	50.45773	Al_2O_3	95.33805
Platinum	Pt	2.612816	Pt	2.612816
Nitrogen	N	1.23985	N	1.23985
Silver	Au	0.809285	Au	0.809285
Oxygen	O	44.88032		
Total		100		100

5. Preparation of the composite PCM and the effect of adding (Al_2O_3) to Iraqi paraffin wax on the thermal conductivity of the compound

With the aim of creating the optimal mixing ratio for the Iraqi paraffin wax and the (Al_2O_3) powder to form the composite PCM; five samples were prepared with weight ratios of Al_2O_3 of 2%, 4%, 6%, 8% and 10%. The experimental procedure involved the following steps:

The weigh: The first step was to weigh each of the paraffin wax and the (Al_2O_3) to be added using the electronic scale (See Figure (4)).

Figure (4): Electronic scale

Heating: The paraffin wax was heated to 45°C until it reached a viscous liquid state without completely melting using an electric heater (See Figure (5)).

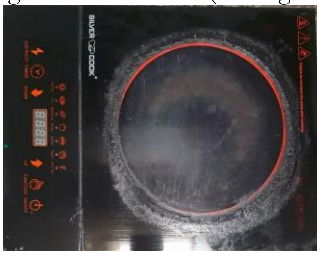


Figure (5): Electric Heater

Mixing: The predetermined weight percentages of Al_2O_3 were added to the wax while maintaining homogeneity. The mixture was thoroughly mixed using an electric mixer (See Figure (6)).

Figure (6): Electric mixing device

Molding: The mixture was poured into gelatinous molds with dimensions of 40 mm diameter at a thickness ranging from 3-6 mm.

Cooling: The samples were allowed to cool until they reached the required hardness.

5.1. Examination of the compound material

The five samples were subjected to a thermal conductivity test using a disc thermal conductivity tester in a laboratory setting.

The thermal conductivity of the paraffin wax obtained to be of 0.21 (W/m.°C). Table (7) gives the results for the different samples and Table (8) shows the images and information of each sample.

Table (7): Test results for the conductivity of the compound material at different percentage of Al_2O_3

Percentage of (Al_2O_3) in the paraffin wax	Sample thickness (mm)	Thermal conductivity (W/m.°C)
2%	5.08	0.28934
4%	5	0.616781
6%	5.05	1.026722
8%	5.79	1.185206
10%	5.2	1.282666

Table (8): Images of the samples and their details

Sample Number	images	Details
1		5-gram paraffin +0.1-gram Al2O3 The percentage of the additive (2%)
2		5-gram paraffin +0.2-gram Al2O3 The percentage of the additive (4%)
3		5-gram paraffin +0.3-gram Al2O3 The percentage of the additive (6%)
4		5-gram paraffin +0.4-gram Al2O3 The percentage of the additive (8%)
5		5-gram paraffin +0.5-gram Al2O3 The percentage of the additive (10%)

5.2. The relationship between the percentage of (Al_2O_3) and thermal conductivity of the compound (wax and powder)

It can be shown from Figure (7) that the thermal conductivity of the compound (wax + Al_2O_3) increases with the increase in the percentage of the added powder up to the highest percentage of 10%. The rate of increase is found to be lower after (6%) of the added material.

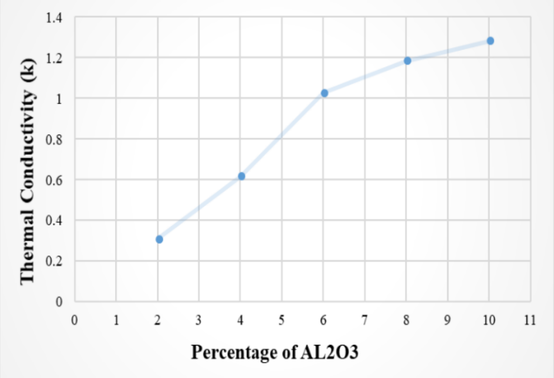


Figure (7): The relationship between the percentage of (Al_2O_3) in the compound and thermal conductivity

5.3. Preparation of the phase change composite material research

The paraffin wax inside the container (See Figure (8)) was heated using an electric heater (See Figure (5)) until the wax began to liquefy. Throughout the melting process, we never fully convert the wax to a fully liquid state. Instead, an electric mixing device (See Figure (6)) was used during melting.

Figure (8): The container contains Iraqi paraffin wax

After the wax was partially cooled, various impurities appeared on the surface and were carefully collected, as shown in Figure (9). After filtration, the wax takes the shape shown in Figure (10). Next, we repeated the heating and partial cooling process.

At this stage, we introduced aluminum oxide (Al_2O_3) into the paraffin wax according to the chosen percentage (6%), which resulted in converting the Iraqi paraffin wax into an enriched form containing aluminum oxide. As shown in Figure (11).

Figure (9): Impurities collected from Iraqi paraffin wax

Figure (10): The Iraqi paraffin wax after filtration

Figure (11): The Iraqi paraffin wax enriched with aluminum oxide (Al_2O_3)

5.4. The steps involving the conversion the PV module into a Hybrid PV/T unit containing PCM and (Al_2O_3)

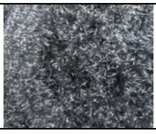
Step 1: A copper tube, as outlined in Table (2), was employed for the circulation of water. The tube underwent bending with a specialized tool, utilizing a 10 cm diameter die. It is noteworthy that no welding was employed in the construction of the pipeline. Instead, it was affixed to the backside surface of the PV panel using R.T.V. silicon, as detailed in Appendix D-1. The tube's placement was strategically selected to optimize its path, ensuring the longest route possible to maximize the capture and utilization of excess heat (Figure (12)), which could otherwise compromise the solar panels' efficiency. This same approach was employed in the second panel of our study to facilitate a comparative analysis between PV and PV/T systems.

Figure (12): The route taken by the copper tube placed at the backside of the solar panel.

Step 2: Based on the findings of research [3], it was discovered that the thermal storage capabilities of the PCM could be improved by introducing metallic swarf containing aluminum, copper, and iron additives. In this study, stainless steel swarf was introduced and evenly distributed to enhance the thermal conductivity between the composite PCM and the backside surface of the solar panel (Figure 13). Additionally, two separate studies, [٤] and [5] emphasized increasing the efficiency of photovoltaic (PV) panel by incorporating porous media in the form of aluminum shavings and aluminum foam matrix, respectively. Details of the steel swarf utilized in this investigation can be found in Table (9).

Figure (13): The method of applying a layer of stainless-steel swarf to the backside surface of the PV panel.

Table (9): Properties of the swarf used in this study

Material	stainless steel swarf
Color	Silver
Type	Stainless Steel 304
Origin	China
Melting point	~ 1415°C
Thermal conductivity	16.3 W/(m.K) (100°C)
Specific heat capacity	500 J/(kg·K) at 0-100 °C
Thermal diffusivity	3.84 mm^2/s at 20-100 °C
Image	

Step 3: Proceed with the installation of the thermocouple temperature sensors, following the depicted arrangement shown in Figure (1).

Step 4: Pouring the paraffin wax into the backside container of the solar panel to form a cohesive mixture that includes the composite paraffin wax, the stainless steel swarf and the copper tube distributed throughout. See Figure (14).

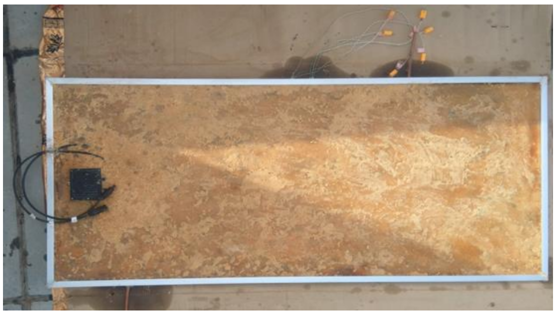


Figure (14): The back side of the solar cell after adding the composite paraffin wax.

Step 5: To protect the added components of the solar panel, it was necessary to create a back cover for the panel, as given in Table (10). The cover is firmly attached to the backside surface of the solar panel. However, a big hitch appeared during the hot summer days when the wax began to melt completely. To prevent any leakage of material from the back cover, a variety of insulating materials were used, including PU Foam Insulation Sealant and Leakage Sealing Tape Super Strong Aluminum (See Figure (16) and (17)) respectively. This material was applied to the cover from the outside, as shown in the Figure (15). These measures have been implemented to ensure that the PCM remains safely contained within the solar panel back container.

Table (10): The backside Cover of the PV/T solar panel

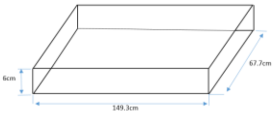
Cover material	Aluminum
Origin	Turkey
Cover Length	149.3cm
Cover Width	67.7cm
Cover Thickness	6 cm
Plate Thickness	1mm
Image	
Dimensions	

Figure (15): The final shape of the PV/T solar panel after modifications

Figure (16): PU Foam Insulation Sealant

Figure (17): Leakage Sealing Tape Super Strong Aluminum

5.5. Installation of the PV and PV/T solar panels

The thermocouples (See Figure (18)) were connected to a temperature data logger and USB interface (See Figure 19) to record temperatures at different times. The PV panel is fixed to a stand (See Figure (20)) with the panel directed toward the geographic south [6] at an angle of 15 degrees. The PV panel was connected to a mini digital volt-ampere meter (See Figure (21)) to measure the current voltage of the device after connecting a thermal load represented by a direct current electric lamp with a power of (100 Watts), as shown in the Figure (22).

Figure (18): Thermocouple

Figure (19): Data logger and USB Interface

Figure (20): Stainless steel holder

Figure (21): Mini Digital Voltage – Ampere meter

Figure (22): Mini Digital Voltage-Ampere meter and direct current electric lamp

6. Conclusion

The previous paragraphs highlight the following key points:

1- The possibility of localizing the manufacture of thermal photovoltaic cells incorporating phase change materials in Iraq is clear. The majority of the basic materials in the research are either manufactured locally or readily available in Iraqi markets. There is also the possibility of producing it through local companies.
2- To enhance the properties of Iraqi wax, it is necessary to remove impurities through a heating and cooling process. This purification method is crucial because impurities with lower melting points than wax tend to float during heating.
3- The cost of Iraqi wax is much lower than imported wax, as the cost of one kilogram does not exceed $2, compared to the cost of imported wax, which is approximately $20.
4- Micro-additives are more cost effective than nano-additives in the preparation process.
5- Mixing Iraqi wax with micro-additives is simpler than mixing it with nano-additives, as the latter requires complex laboratory precautions.
6- While the thermal conductivity of Iraqi wax increases with the increase in additives, experiments indicate that the rate of increase decreases after reaching 6% of the additive used in the research.
7- Aluminum oxide is chosen to enhance the wax properties because this material has not previously been applied in the field of improving the performance of photovoltaic systems.
8- The choice of grid shape for the coolant fluid passage in thermal installations attached to PV modules is influenced by different perspectives. The study chose the longest path for the conveyor tube to maximize heat collection and avoid welding operations to prevent clogging and other associated problems.
9- Ensuring that PV module components containing phase change materials are insulated is crucial to prevent leakage during hot summer days. The materials used in the study proved highly effective in preventing such incidents.

10- In academic research, installing a pair of thermal cables at each point where heat is taken is essential. This precaution allows for a backup method in the event of failure of the first thermal cable, as dismantling the system after connection represents a major challenge.

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