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**FACULTY OF TECHNOLOGY**
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# ACADEMIC MASTER

Sector: Science and Technology
Sector: Mechanical engineering
Specialty: Renewable energies

## Theme

# Feasibility study of photovoltaic cooling system using channels of ternary nanofluids

Before the jury composed:

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**2023/2024**

# Dedications

*To the owner of a colorful biography and enlightened thinking.*

*He was the first person*

*To help me get a higher education.*

*(My beloved father), may God prolong his life.*

*To the one who put me on the path of life and made me strong. And who took care of me until I became an adult.*

*(My dear mother), may God prolong her life.*

*To my brothers and sisters, who helped me overcome many obstacles and difficulties.*

*To all my honorable teachers who did not hesitate to help me.*

*I dedicate my research to you at the following address:*

***ER10 Feasibility study of photovoltaic cooling system using channels of ternary nanofluids***

# Thanks

*First of all, we thank God who helped us to complete the task*

*A note that enlightened our path and our success in our scientific mission*

*We thank the kind parents who provided us with all necessary incentives to complete this memorandum We also thank the supervising professors for his efforts*

*They helped us prepare this memo because it provided us with everything that was consistent with our research*

*We thank all the professors and employees at the University of* ***Homa Lakhdar*** *for what they have provided for education in our country*

*The university, in particular the dean and college professors Science and Technology, especially the Department of Mechanics From the head of the department to all the professors*

*Also, do not forget our sincere thanks to all of you Department colleague*

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# General Introduction

# General introduction

Solar panels play a vital role in generating clean, sustainable energy, and as the demand for alternative energy increases, improving the efficiency of these panels becomes crucial. One of the main challenges facing solar panels is the high temperatures resulting from constant exposure to sunlight, which leads to a decrease in their operational efficiency.

Here the importance of phase change materials (PCMs) emerges as an innovative and effective solution for cooling solar panels. These materials have the ability to absorb and store thermal energy and then release it when needed, helping to maintain optimal operating temperatures for the panels. By incorporating phase change materials into the design of solar panels, better thermal balance can be achieved, thus improving overall performance and increasing the efficiency of converting solar energy into electricity.

In this note, we will address the study of the effect of phase change materials on the solar panel cooling process, according to the following chapters

- Chapter 1 will discuss generalities about solar panels
- Chapter II. We will review the research related to phase change materials
- In the third chapter, we will discuss simulating the pv_pcm system using a program ANSYS

# Chapter I:

# Generalities

# I. Chapter I: General

## I.1. Introduction

Heat transfer has four basic modes: conduction, convection, phase change, and radiation. Studying these modes allowed the development of thermal sciences, and the sun is the largest renewable source of heat known to man. Therefore, researchers and developers worked to exploit this source by developing different methods and mechanisms. Photovoltaic and thermal panels are one of the most important mechanisms that are witnessing great development in the field of exploiting solar energy according to the principles of thermal transfer science. In this chapter, we will discuss generalities about heat transfer mechanisms, solar panels, and the effect of heat on them

## I.2. Heat concept

Heat is the form of energy that is transferred between two substances at different temperatures. The direction of energy flow is from the substance of higher temperature to the substance of lower temperature. Heat is measured in units of energy, usually calories or joules.[1]

The zeroth law of thermodynamics states that no heat is transferred between two bodies in thermal equilibrium; therefore, they are equal in temperature.

We can use the heat capacity to determine the heat released or absorbed by a material using the following formula:

$$Q = m \times c \times \Delta T \qquad \text{(I1)}$$

Where;

M; the mass of the substance [g].

C; the specific heat capacity [$\frac{J}{G.K}$].

ΔT; the change in temperature[k]or [℃]

## The concept of Heat Transfer

Heat transfer is thermal energy in transit due to a spatial temperature difference.

Whenever there exists a temperature difference in a medium or between media, heat transfer must occur. As shown in Figure I-1, we refer to different types of heat transfer processes as modes. When a temperature gradient exists in a stationary medium, which may be a solid or a fluid, we use the term conduction to refer to the heat transfer that will occur across the medium. In contrast, the term convection refers to heat trans- fer that will occur between a surface and a moving fluid when they are at different temperatures. The third mode of heat transfer is termed thermal radiation. All sur- faces of finite temperature emit energy in the form of electromagnetic waves. Hence, in the absence of an intervening medium, there is net heat transfer by radiation between two surfaces at different temperatures.

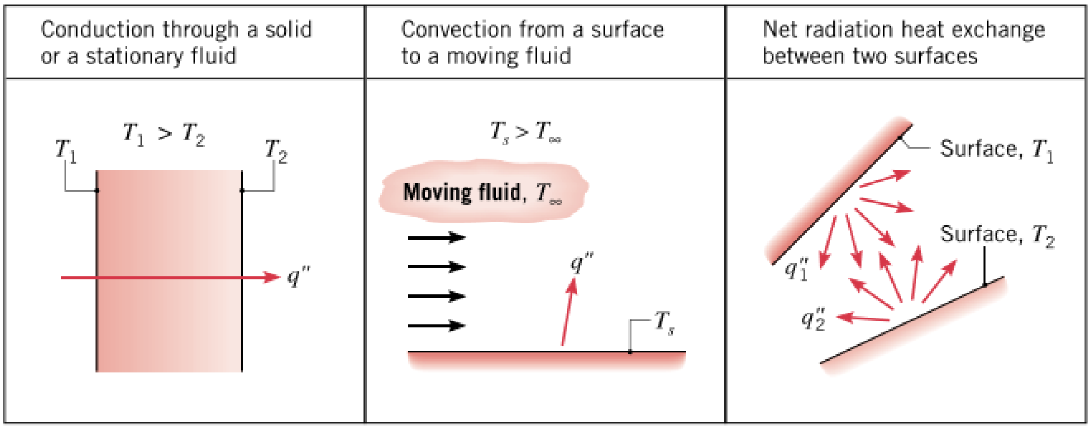


**Figure I-1:**Conduction, convection, and radiation heat transfer modes.

## I.3. Modes of Heat Transfer

### I.3.1. Conduction

It is the transfer of heat from a high temperature medium to a low temperature medium Conduction can be viewed as the transfer of energy from more energetic matter particles to less energetic particles due to interactions between particles. In the presence of a temperature gradient,[2]

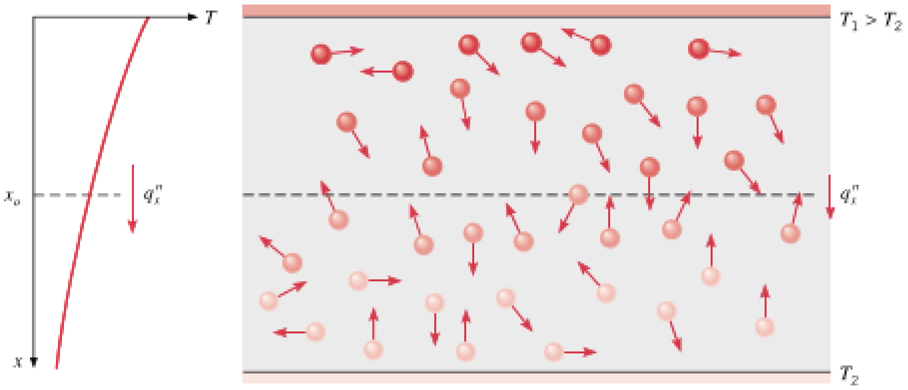


**Figure I-2:** Association of conduction heat transfer with diffusion of energy due to molecular activity[2].

The basic equation for the analysis of heat conduction is Fourier's law, which is based on experimental observations and is:

$$\mathbf{q''_n = -k_n \frac{\partial T}{\partial n}} \quad ( \text{I2})$$

### I.3.2. Convection

The convection heat transfer mode is comprised of two mechanisms. In addition to energy transfer due to random molecular motion (diffusion), energy is also transferried by the bulk, or macroscopic, motion of the fluid. This fluid motion is associated with the fact that, at any instant, large numbers of molecules are moving col-electively or as aggregates. Such motion, in the presence of a temperature gradient, contributes to heat transfer. Because the molecules in the aggregate retain their ran-dome motion, the total heat transfer is then due to a superposition of energy transport by the random motion of the molecules and by the bulk motion of the fluid. It is customary to use the term convection when referring to this cumulative transport and the term advection when referring to transport due to bulk fluid motion.

#### a) Types of heat transfer by convection[2]

**Forced convection** when the flow is caused by external means, such as by a fan, a pump, or atmospheric winds. As an example, consider the use of a fan to provide forced convection air cooling of hot electrical components on a stack of printed circuit boards (Figure 1.5a).

**Free (or natural) convection** the flow is induced by buoyancy forces, which are due to density differences caused by temperature variations in the fluid. An example is the free convection heat transfer that occurs from hot components on a vertical array of circuit boards in air (Figure 1.5b).

Air that makes contact with the components experiences an increase in temp-erature and hence a reduction in density. Since it is now lighter than the surround-Ing air, buoyancy forces induce a vertical motion for which warm air ascending from the boards is replaced by an inflow of cooler ambient air.

While we have presumed pure forced convection in Figure 1.5a and pure natural convection in Figure 1.5b, conditions corresponding to mixed (combined)forced and natural convection may exist.

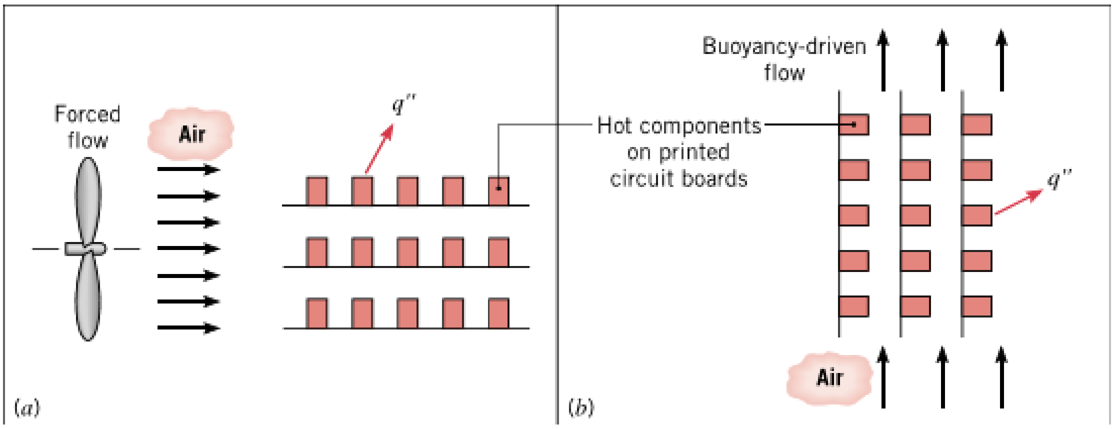


**Figure I-3:** Convection heat transfer processes. (a) Forced convection. (b) Natural convection.[2]

### b) The controlling equation for convection

The controlling equation for convection is Newton’s Law of Cooling

$$q" = hA(T_s - T_\infty) \qquad (I3)$$

Where;

$q"$:the convective heat flux $(\frac{W}{m^2})$,

$T_S$ : is the surface temperature

$T_\infty$:is the fluid temperature

A: is the surface area of the solid

h is the convection heat transfer coefficient in $(\frac{W}{m^2}K)$

### c) Characteristics of the heat transfer coefficient by convection

h is also called the heat transfer coefficient of the film or surface conductivity and its value depends on[3]:

- Surface condition: roughness and cleanliness
- Geometry and orientation of the surface: plate, cylinder or sphere, placed vertically or horizontally.
- Thermophysical properties of the fluid: density, viscosity, specific heat, thermal conductivity etc.
- Nature of fluid flow: laminar or turbulent
- Boundary layer configuration
- Prevailing temp. conditions.

### I.3.3. Radiation

Heat is transferred by radiation between objects, surfaces, and fluids that are far apart and have different temperatures in the form of electromagnetic waves whose speed is approximately equal to the speed of light (3 x 10 8 m/s), so heat transfer by radiation is considered the fastest way to transfer heat (faster than heat transfer by heat Of all kinds and heat transfer by conduction).

When studying the process of heat transfer by radiation, it is necessary to study and know the properties of thermal radiation, and also to study and know Stefan Boltzmann’s law for black bodies. Finally, the process of heat transfer by radiation between bodies or surfaces of different temperatures depends on the shape of the surface area or body radiating heat and the distance between the bodies, as well. We must know that the thermal radiation emitted from one body does not reach completely the other body with which it exchanges heat, but rather part of it is lost. All of these factors are governed by a factor called the radiation form coefficient.

The basic rate equation for radiation HT is the Stefan Boltzmann law:

$$E_b = \sigma_b A T^4 \qquad (\text{ I4})$$

Where;

$E_b$ is the energy radiated per unit time.

T is the absolute temp of the surface

$\sigma_b$is the Stefan-Boltzman constant

$\sigma_b$= 5.67 x $10^{-8}10-8\ \frac{W}{m^2K^4}$

## I.4. Solar panels

Solar Photo Voltaic Panel is the key part of a solar photo voltaic power generation system. This articles briefs on the various components of a solar photo voltaic panel.

The solar photo voltaic panels are kept outside facing the sunlight. The PV panel converts the sunlight in to DC electricity. The solar photo voltaic panel is generally of three types 1. Poly Crystalline solar panel 2. Mono Crystalline solar panel and 3. Thin Film panel. The crystalline panels are made of crystalline silicon while the thin film panels are made of technologies such as cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous thin-film silicon (a-Si, TF-Si)

## I.5. Types of Solar Panels

The solar panels can be divided into 4 major categories[4]:

### I.5.1. Monocrystalline solar panels

The monocrystalline solar panels are also known as the single crystal panels. They are made from pure silicon crystal which is sliced into several wafers forming cells. These wafers are cut to an octagonal shaped wafer because of which they get their unique look and uniform colour. They can be easily identified by their black or dark blue colour, as they are made from pure silicon.

Within monocrystalline solar panels, there is a technology known as Half Cut cells. Here the square shaped cells are cut in half, so there are twice the number of cells. The top half of the panel has all cells connected in one series and the bottom half in another series. This allows the panel to continue power generation in the top half even if there is a shadow on the bottom half of the panel. Thus, the overall power generation from half cut cells is higher in installations with partial shadow issues.

**Figure I-4:** Monocristalline Solar panels[5]

### I.5.2. Polycrystalline solar panels

The polycrystalline solar panels are composed of multiple silicon crystals. They are made from silicon fragments that are melted and poured into square molds. Once these crystals are cooled, they are sliced into thin wafers and assembled together to form a polycrystalline solar panel. They are also known as “multi-crystalline” panels

**Figure I-5:** Polycristalline panels[5]

### I.5.3. Passivated Emitter and Rear Contact cells (PERC) solar panels

Also known as ‘rear cells’, PERC solar panels are manufactured using advanced technology. It is done by adding a layer on the back of solar cells. The traditional solar panels absorb sunlight only to some extent and some light passes straight through them. The additional layer in the PERC panels allows this unabsorbed sunlight to be absorbed again from the rear side of the panels, making it even more efficient.

Nowadays, PERC technology is typically combined with Monocrystalline cells to produce high efficiency Mono-PERC panels which have the highest power ratings among commercially available solar panels.

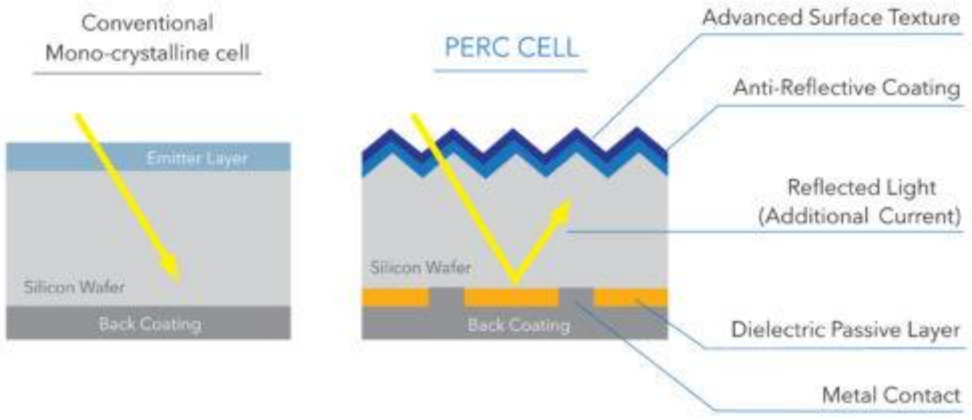


**Figure I-6 :** Passivated Emitter and Rear Cell (PERC) Solar Panels**[6]**

### I.5.4. Thin-film solar panels

Unlike monocrystalline and polycrystalline solar panels, thin-film solar panels are manufactured using photovoltaic substances which include Amorphous silicon (a-Si), copper indium gallium selenide (CIGS) and cadmium telluride (CdTe). These substances are deposited onto a solid surface such as glass, metal or plastic making it lighter and easy to install.

### I.5.5. The Components of a Solar Panel

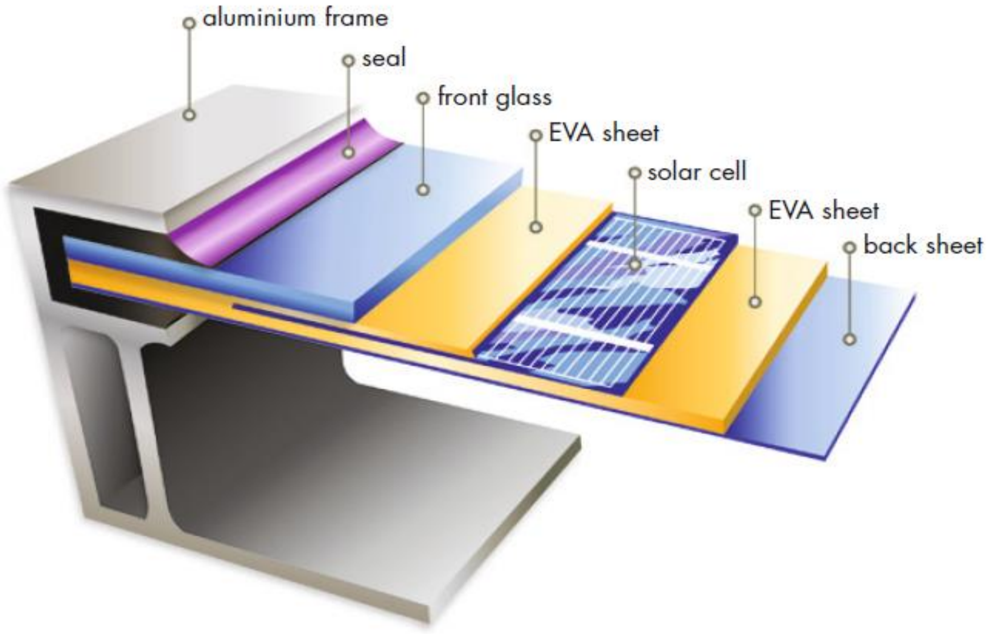


**Figure I-7:**Components of a Solar PV panel[7]

- **Solar Cells:** Solar cells are the key component of a solar panel system. They consist of multiple layers of semiconductors that create electric charges when exposed to sunlight. These charges are then collected by the busbars and transported to the connectors, starting the process of converting sunlight into electrical energy[8].

  Various factors govern the electricity generated by a solar cell such as;The intensity of the light: Higher sunlight falling on the cell, more is the electricity generated by the cell.

  Cell Area: By increasing the area of the cell, the generated current by the cell also increases.

  The angle of incident: If the light falling on the cell is perpendicular to its surface, the power generated by it is optimum. Ideally, the angle should be 90o but practically it should be as close as 90o.

- **Solar Glass:** is a protective covering that maximizes sunlight absorption while shielding solar cells from harsh weather and debris. It is designed to capture the sun's energy while preventing external elements from damaging the delicate cells. This transparent barrier allows sunlight to pass through while safeguarding the cells, ensuring maximum efficiency and longevity[8].

- **The back sheet:** is like the bodyguard of a solar panel system, protecting the delicate solar cells from external forces such as moisture, heat, and debris. This unsung hero acts as a barrier, ensuring the longevity and efficiency of the solar panel. Without it, the solar cells could be permanently damaged, rendering the entire system useless[8].

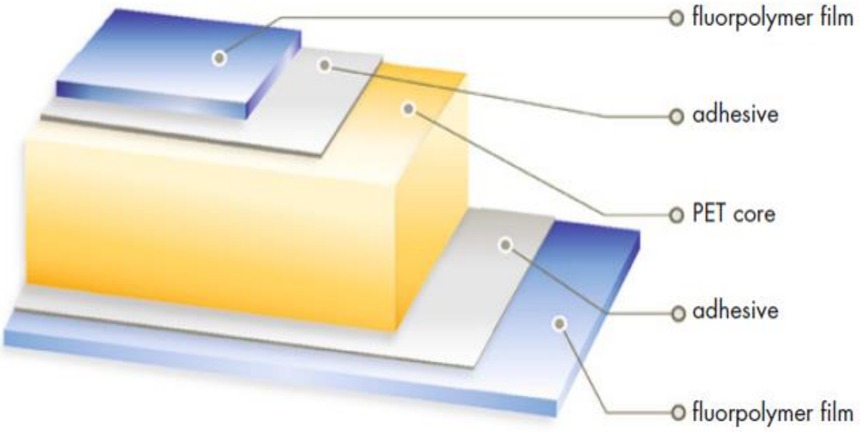


**Figure I-8:** Back Sheet of solar PV Panel[7]

- Framing: is like the backbone of a solar panel system, providing crucial structural support and protection for delicate solar cells. Different materials like aluminum and steel are used to construct sturdy frames that help maintain the shape of the panel and maximize energy absorption. This vital component ensures the panel's durability and efficiency[7]

**Figure I-9:**Aluminum Frame[7]

- Junction Box and Diodes: junction box is located at the back side of the solar pv panel. The connections from the solar cells ends at the junction box. The box is made to with stand the temperature and the external forces for the entire life time of the solar panel. The junction box encloses diodes to make sure that the power flow is uni directional i.e., from the panels to the external connection. It also prevents power flowing in to solar panels during the night-time. [7]

**Figure I-10:(**A) Junction Box;(B) Diode in Solar Panels[7]

## I.6. Caractéristiques of photovoltaïque panel[9]

The cell parameters are given by manufacturers at the STC (Standard Test Condition). Under STC the corresponding solar radiation is equal to 1000 W/m2 and the cell operating temperature is equal to 25oC. The Solar cell paramètres are as follow ;

### I.6.1. Short circuit current ($I_{SC}$):

Short circuit current is the maximum current produced by a solar cell, measured in amperes (A) or milliamperes (mA). The open circuit voltage is zero when the cell produces maximum current (ISC = 0.65 A).

The value of short circuit depends on cell area, solar radiation on falling on cell, cell technology, etc. Sometimes the manufacturers give the current density rather than the value of the current. The current density is denoted by “J” and the short circuit current density is denoted by “JSC”. The short circuit current density is obtained by dividing the short circuit current by the area of the solar cells as follow:

$$\boldsymbol{J_{SC}} = (\boldsymbol{I_{SC}})/(\boldsymbol{A}) \tag{I5}$$

### I.6.2. Open Circuit Voltage ($V_{OC}$) :

Open circuit voltage is the maximum voltage a cell can produce under open circuit conditions. It is measured in volts (V) or millivolts (mV). The short-circuit current is zero when the cell produces maximum voltage. The $V_{OC}$ value depends on the cell technology and the operating temperature of the cell.

### I.6.3. Maximum Power Point ($MPP$ ):

Maximum power point represents the maximum power that a solar cell can produce at the STC (i.e. solar radiance of $1000W/m^2$ and cell operating temperature of 25℃). It is measured in $W_{Peak}$ or simply $W_P$. Other than STC the solar cell has $P_M$ at different values of radiance and cell operating temperature. The cell can operate at different current and voltage combinations. But it can only produce maximum power $P_M$ at a particular voltage and current combination.

$$\boldsymbol{P_M} = \boldsymbol{I_M} \times \boldsymbol{V_M} \tag{I6}$$

### I.6.4. Current at maximum power point ($I_M$):

It represents the current that a solar cell will produce when operating at maximum power point. It is denoted by $I_M$ and its value is always less than the short circuit current ($I_{SC}$). It is measured in amperes (A) or milliamperes (mA).

### I.6.5. The Voltage at Maximum Power Point ($V_M$):

It represents the voltage that a solar cell will produce when operating at maximum power point. It is denoted by $V_M$ and its value is always less than the open circuit voltage ($V_{OC}$). It is measured in volts (V) or millivolts (mV).

### I.6.6. Fill Factor (FF):

It represents the area covered by $I_M - V_M$ rectangle with the area covered by $I_{SC} - V_{OC}$ rectangle as by dotted lines in Figure (I- 8). The fill factor represents the squareness of the I – V curve. It is represented in terms of the percentage (%), the higher the fill factor in percent the better is the cell.

$$FF = P_M / (I_{SC} \times V_{OC}) \qquad \text{I7)}$$

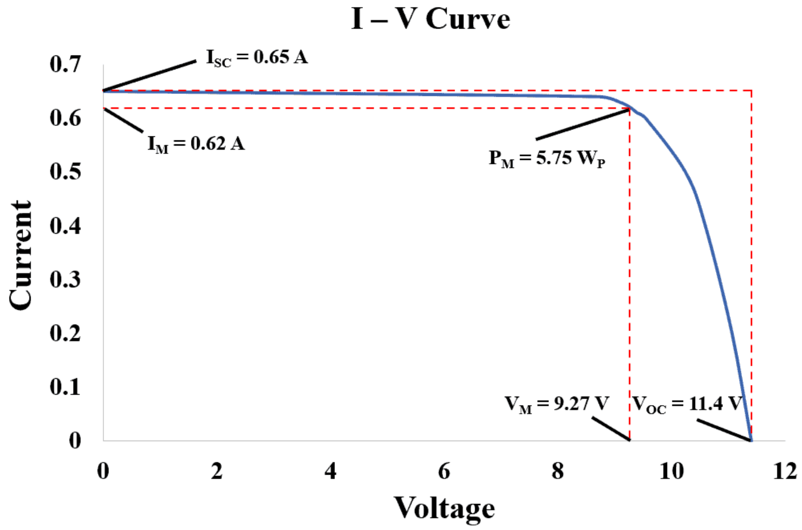


**Figure I-11:** the I – V Curve

### I.6.7. Efficiency (η):

A solar cell efficiency is defined as the maximum output power ($P_M$) divided by the input power ($P_{IN}$). It is measured in percentage (%), which indicates that this percentage of input sunlight power is converted to electrical power. The efficiency can be calculated as follows;

$$\eta = \frac{\boldsymbol{P_M}}{\boldsymbol{P_{IN}}}(\times \ \boldsymbol{Area}) \qquad \text{( I8)}$$

## I.7. Effect of temperature on solar panels

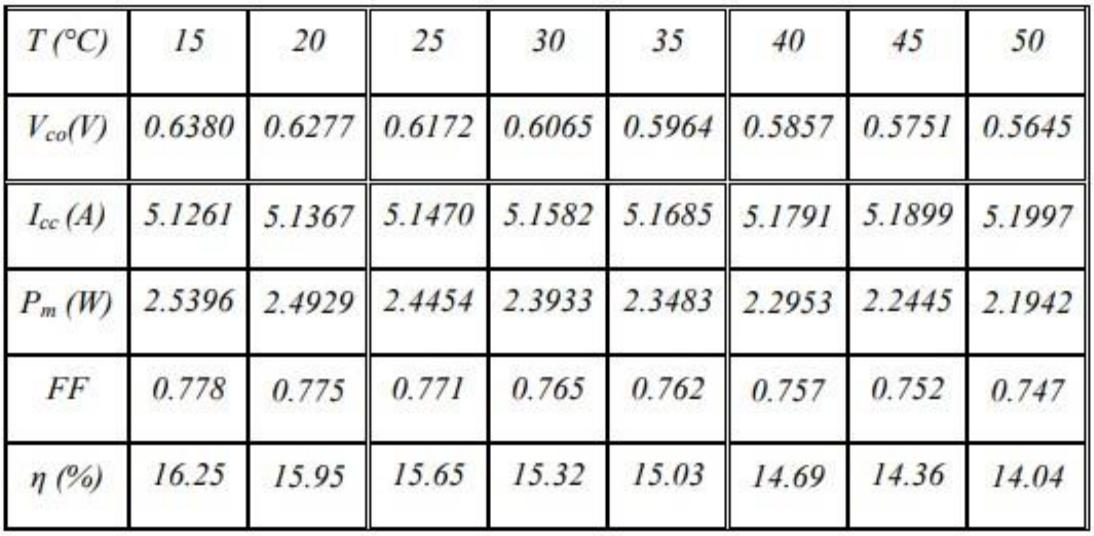
Temperature has a deleterious effect on the operation of photovoltaic panels. As the cell temperature rises, the power and voltage of the solar panel lowers, and the current (intensity) increases slightly. The effect of the outside temperature on the photovoltaic module has an impact on its performance.

Manufacturers indicate on the technical sheet of photovoltaic panels the maximum power of the module under STC condition and mention 3 types of temperature coefficients: short-circuit current temperature coefficient ($\boldsymbol{I_{CC}}$); open circuit voltage temperature coefficient ($\boldsymbol{V_{OC}}$); temperature coefficient at the maximum power point

($P_M$). Each of the values (current, voltage and power) varies by a certain percentage with each change in cell temperature.[10]

Table (I. 1) shows the evolution with temperature of the open circuit voltage ($\boldsymbol{V_{OC}}$), the short circuit current ($\boldsymbol{I_{CC}}$), the maximum power extracted from the cell ($\boldsymbol{P_M}$), the form factor (**FF**) and the photovoltaic conversion efficiency (**η**).

**Table I-1:Evolution with temperature of ($V_{OC}$), ($I_{CC}$), ($P_M$), (FF) and (η)[11].**



| $T$ (°C) | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|
| $V_{co}$(V) | 0.6380 | 0.6277 | 0.6172 | 0.6065 | 0.5964 | 0.5857 | 0.5751 | 0.5645 |
| $I_{cc}$ (A) | 5.1261 | 5.1367 | 5.1470 | 5.1582 | 5.1685 | 5.1791 | 5.1899 | 5.1997 |
| $P_m$ (W) | 2.5396 | 2.4929 | 2.4454 | 2.3933 | 2.3483 | 2.2953 | 2.2445 | 2.1942 |
| FF | 0.778 | 0.775 | 0.771 | 0.765 | 0.762 | 0.757 | 0.752 | 0.747 |
| η (%) | 16.25 | 15.95 | 15.65 | 15.32 | 15.03 | 14.69 | 14.36 | 14.04 |

## I.8. Factors That Affect Solar Panel Efficiency

In addition to temperature, a variety of factors can affect the performance and efficiency of solar energy, including[12]:

- **Sunlight:** The amount of direct sunlight a PV panel receives is typically the most significant determiner of how much electricity it can produce. Even the most efficient solar panel can’t generate electricity at night, and production is diminished on overcast days.
- **Orientation and Tilt:** Orienting panels towards the sun (facing south if you are in the Northern Hemisphere) to maximize sunlight exposure is best. Depending on your latitude, you can optimize their efficiency by angling them directly toward the sun’s path — around 30-45 degrees.

- **Dust, Snow, and Debris:** Dirt, leaves, snow, and other debris can block sunlight from the panels. Be sure to clean your solar panels regularly to keep them efficient.
- **Panel Age:** As photovoltaic panels age, their efficiency will slowly decrease year after year. Having said that, high-quality solar panels can last 25 years or more — longer than an asphalt roof.
- **Shading:** If shadows from nearby trees or structures block your panels, they won’t reach maximum efficiency. This issue also goes for partial shading — if one cell in a monocrystalline or polycrystalline PV panel is in the shade, the cumulative electricity generation capacity of the panel will be adversely affected.

## I.9. Conclusions

In this chapter, we have touched on the concept of heat and heat transfer mechanisms, and we have presented details about photovoltaic solar panels by mentioning their types, their components, and the effect of a temperature factor on their effectiveness.

# ChaptrII: Development
# Of
# PV-PCM research

# II. Development of PV-PCM research

## II.1. Introduction

Solar energy is one of the most prominent sources of renewable energy, as photovoltaic solar panels are used to convert sunlight into electricity. However, the performance of these panels is affected by several environmental factors, the most notable of which is temperature. Although solar panels rely on sunlight to generate electricity, high temperatures can significantly reduce their efficiency. In response to this problem, the researchers worked to develop technical solutions to improve the efficiency of panels in hot environments by creating designs for systems that cool the solar panel. We find that the PV-PCM system received great development due to the interest of researchers in it, as many research papers were published about it.

In this chapter we will review the literature on the PV-PCM system

## II.2. A review of the literature on PV-PCM system

According. To Mahamudul et al." Temperature Regulation of Photovoltaic Module Using Phase Change Material: A Numerical Analysis and Experimental Investigation " International Journal of Photoenergy, 26 April 2016

Numerical and experimental analysis showed that the application of phase change materials (Figure II -1) is able to regulate the temperature of the PV module by 10 °C for about 6 hours in Malaysian weather. Which greatly enhances the conversion efficiency of the photovoltaic module.[13]

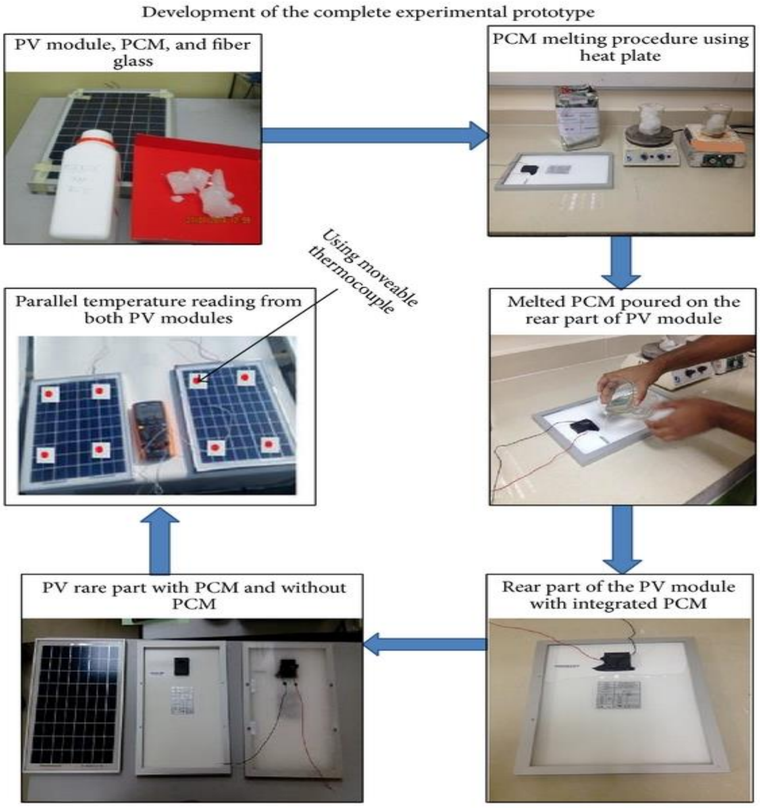


**Figure I-12:***Development of the complete experimental prototyp*

According. To Ahmad Hasan et al," *Impact of integrated photovoltaic-phase change material system on building energy efficiency in hot climate* ". Energy and Buildings130, P 495-505. 15 October 2016,

They developed a PV-PCM system by adding a PCM layer behind the PV and an insulated chamber behind the PV-PCM to mimic a miniature internal space. The effect of the added PCM layer on the electrical and thermal energy efficiency of PV and indoor space, respectively, was studied experimentally in a warmer climate. Reduction in PV transient temperature, internal transient temperature, and delay in peak internal temperature observed through the use of PCM. As a result, an increase in PV energy production of 7.2% at peak and 5% on average was observed along with an enhanced internal cooling effect of 9.5% at peak and 7% on average during the day.[14]

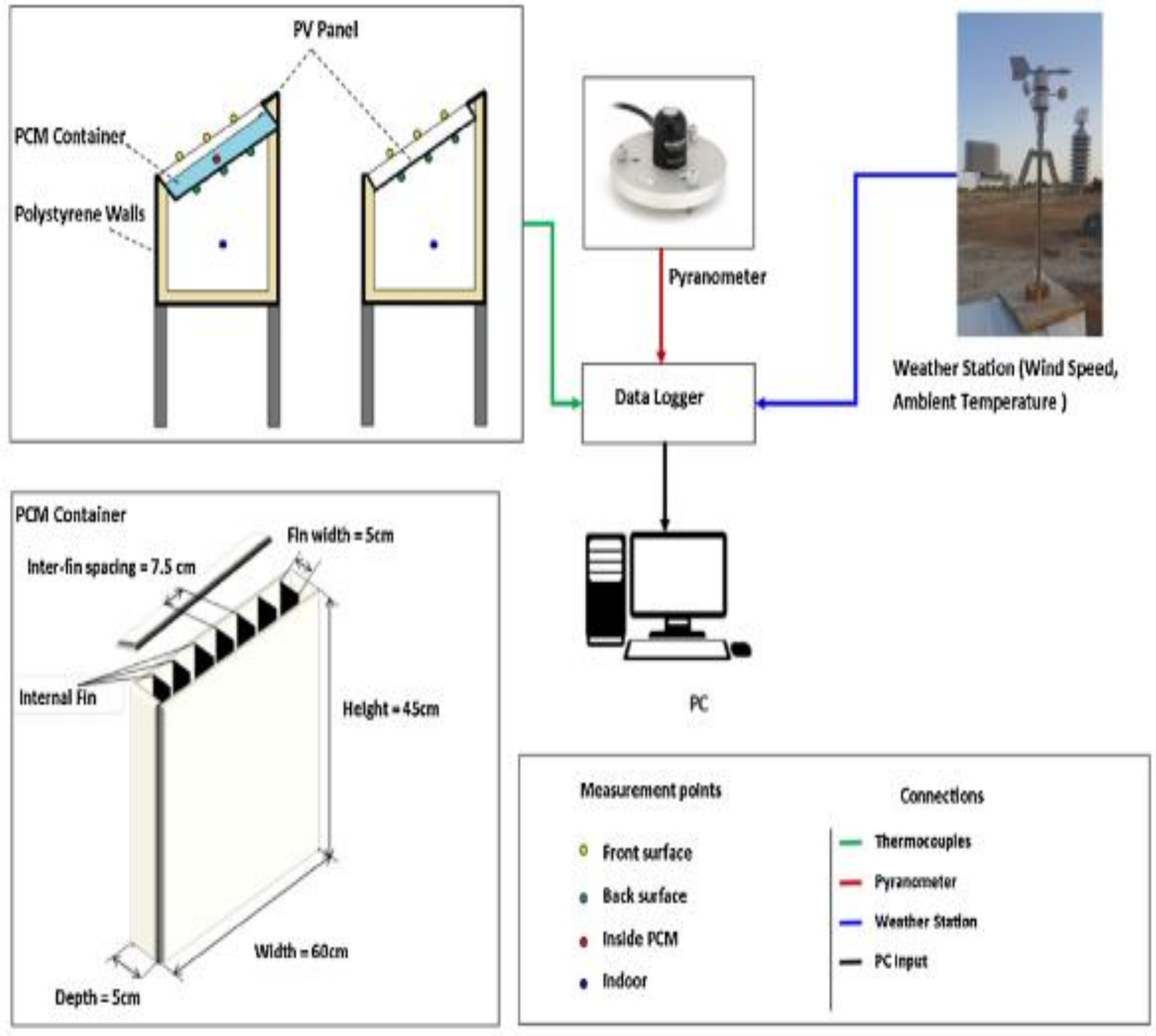


**Figure I-13:***Schematic diagram of the setup.*

According. To Lim et al" *Diurnal Thermal Behavior of Photovoltaic Panel with Phase Change Materials under Different Weather Conditions* " energies 2017;10:

They evaluated the feasibility of PV-PCM systems under the local climate. Using two different PCM models, the thermal behavior of the PV-PCM system was simulated under different climatic conditions in different seasons, showing an average operating temperature drop of 4°C[15]

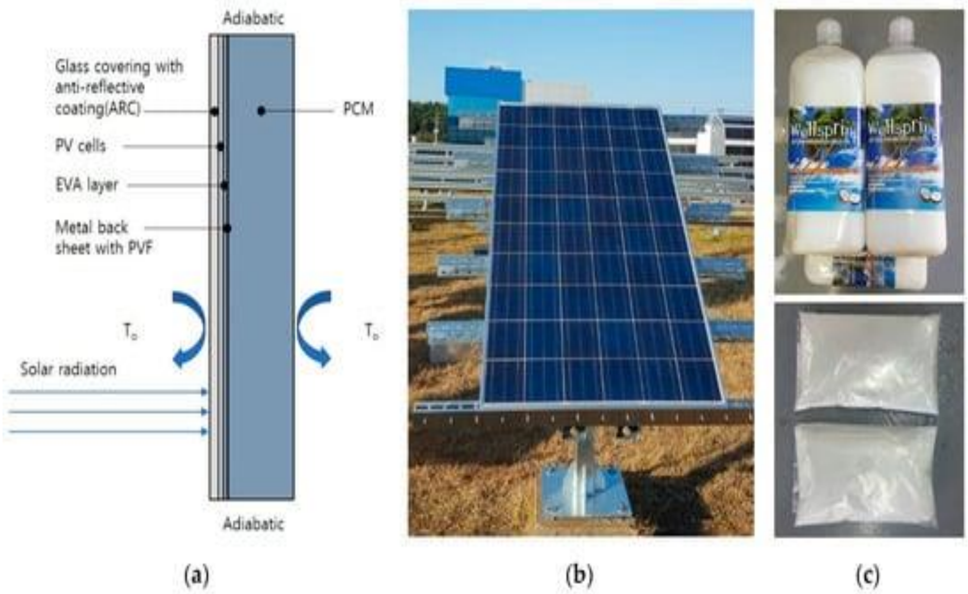


**Figure I-14:***Thermal model for PV panel with PCMs: (a) schematic diagram of thermal model; (b) and example of a polycrystalline PV panel; and (c) an example of a PCM and macro-type container in the nylon bag.*

According. To Razali Thaib et al," *Experimental analysis of using beeswax as phase change materials for limiting temperature rise in building integrated photovoltaics* " Case Studies in Thermal Engineering 2018

Experimental results for one day in an outdoor environment for a PCM system (Figure II 2) where beeswax and paraffin were used as PCM showed that the efficiency of the PV panels increased from 6.1%-6.5% to 7.0%-7.8% This proved that the water cooling process is able to increase the efficiency of PV panels[16].

**Figure I-15:** *Outdoor experimental setup consisting of a reference PV, PV-PCM1 and PV-PCM2 installed*

According. To Dianhong Li et al*" Conversion efficiency gain for concentrated triple-junction solar cell system through thermal management";* Renewable Energy 126, 960-968 October 2018

Thermal photovoltaic system was integrated with PSM and they conducted a comprehensive experimental study to verify the performance of the open-air system to reveal the influence of cooling methods, sunlight intensity, and focused light spot uniformity on the conversion efficiency of the system.

The efficiency of photovoltaic cells with PCMs was 0.56% higher than that of the photovoltaic system[17].

**Figure I-16:***Photographs of the experiment system, (a) the aluminum alloy frame of the system, (b) the Fresnel lens,(c) the triple-junction solar cell and the PCMs module, and (d) the TE module and water-cooled plate*

According. To Zhenpeng Li et al *"Experimental study and performance analysis on solar photovoltaic panel integrated with phase change material" Energy* 178, 471-486 1 July 2019

They designed a system that uses phase change material (PCM) to absorb excess heat from the PV module to regulate the PV temperature and improve electrical efficiency. Furthermore, a PV-PCM-T system, i.e. integrated with a Solar thermal (ST) collector to further utilize the heat stored in the PCM, is also examined for comparison. To evaluate the operating performance of the system in practical application, the PV-PCM module and the new PV-PCM-T module were tested under real outdoor conditions. The results show that the PV temperature difference between the PV-only system and the PV-PCM system can reach 23°C, thus The electricity production of the PV-PCM system increases by 5.18%. Moreover, the total energy production of the PV-PCM-T system is evaluated by introducing three indicators, namely total energy, energy total and electrical total, which are calculated as 3088, 1920 and 2312 kJ/day, with an increase of 74.3%, 8.32% and 30%. 4%, respectively[18].

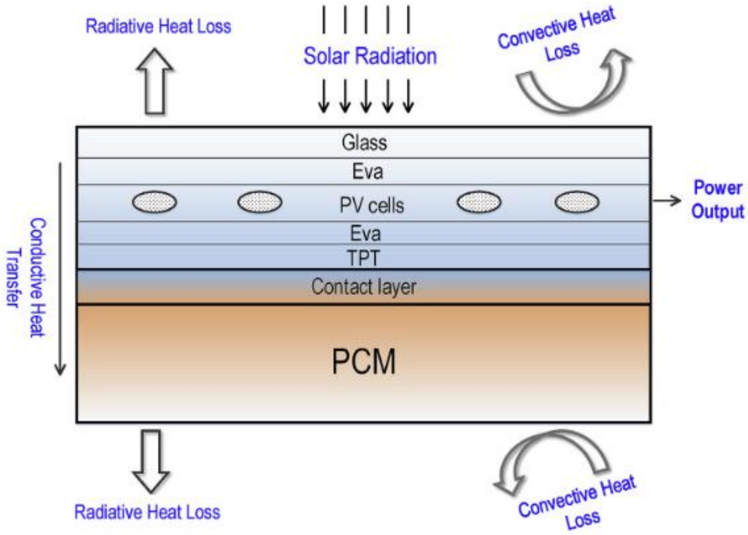


**Figure I-17:***Configuration of a typical PV-PCM system and the energy flow path.*

According. To Stefano Aneli "*Numerical Simulations of a PV Module with Phase Change Material (PV-PCM) under Variable Weather Conditions*" International Journal of Heat and Technology Vol. 39, pp. 643-652 April, 2021,

They evaluated the performance of a conventional photovoltaic panel in which two organic PCMs (PV-PCM) are added to reduce the temperature rise of the photovoltaic cells, by performing unsteady-state numerical simulations using Ansys Fluent software.

Results indicated that PV-PCM modules allow achieving higher performance compared to conventional PV modules, especially during the hotter months. An increase in maximum power of 10% and 3.5% of energy produced over the year has been achieved[19]

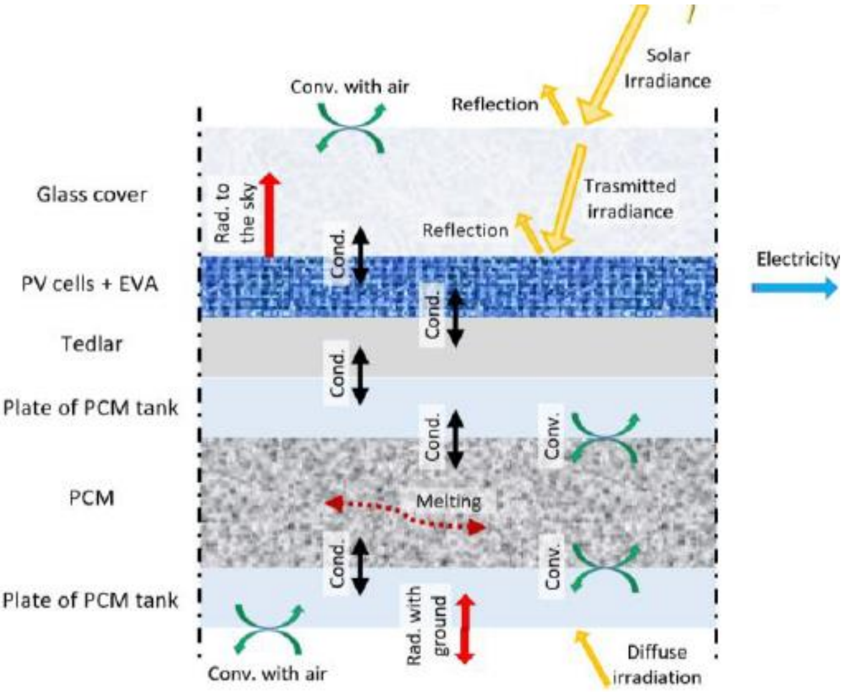


**Figure I-18:** *Heat fluxes in PV-PCM unit*

According. To Zhenyu Luo et al" *Simulation study on performance of PV-PCM-TE system for year-round analysis* " Renewable Energy 195, P263-273 August 2022,

A new photovoltaic system integrated with phase change material (PCM) and photovoltaic module (TE) is proposed. They studied the annual dynamic performance of the proposed system by creating a numerical model focusing on the temperature of the solar cells, their efficiency, and the resulting energy. The efficiency of the PV-PCM-TE system is increased by 10.15% and 2.37% compared with the single PV system and PV-TE system, respectively. It was confirmed that the performance of the PV-PCM-TE system was the best. Compared with PV-TE system, the efficiency increased by 3.53% in summer and 0.6% in winter,[20]

According. To Abdelrazik A. S. et .al *"NSYS-Fluent numerical modeling of the solar thermal and hybrid photovoltaic-based solar harvesting systems* "148 ,11373–11424, (2023)[21]

As part of the study they evaluated the results and made some observations explaining various important additional information such as the radiation applied and the melting/solidification patterns. Besides, validation and error checking techniques between experimental and simulation work are presented. Overall, the results of ANSYS-Fluent CFD were validated and it was possible to optimize many design parameters with minimal effort and cost. Recent research has indicated that nanofluids can be a better alternative to conventional fluids to improve the thermal function of flat panels and hybrid PV/T systems. Efficient cooling mechanisms can reduce the temperature of PV panels by 15-20%. Furthermore, integrating PCM with PV systems can boost efficiency by 33-46% on summer days. By incorporating different nanomaterials and using micro-PV/PCM configurations, the PV/PCM system showed improved cost-effectiveness, while the foam layer outside the PCM could increase the PV thermal management time by 55%. Inside they highlight many other conclusions about commonly used physical models, solution methods, and assumptions dealing with different systems.

According. To Sukru Bestas et al "*A bibliometric and performance evaluation of nano-PCM-integrated photovoltaic panels: Energy, exergy, environmental and sustainability perspectives*"Renewable Energy; 226, May 2024

The researchers conducted a comparative study of five systems: A reference PV panel, a cooled PV panel using PVs without nanoparticles (PVPCM-0), and PV panels containing PVs with different concentrations of nanoparticles (PVPCM-0.05, PVPCM-0.1, PVPCM-0.1, and PVPCM-0.15). Among the five different systems, the PV panel with 0.15% nanoparticles (referred to as PVPCM-0.15) showed the most effective cooling capacity. Furthermore, the PVPCM-0.15 system delivered the highest performance with a 19.49% increase in panel power output. The average energy and power efficiency values for the PV systems were 9.06% and 3.79% for PV panels, 9.60% and 5.15% for PVPCM-0.05, 9.70% and 5.12% for PVPCM-0.05, 10.28% and 6.01% for PVPCM-0.1, and 10.44% and 7.29% for PVPCM-0.15[22].

## II.3. conclusion

In this chapter we have reviewed the literature on the PV-PCM system which has shown us its importance in increasing the efficiency of photovoltaic panels

# Chapter III: presentation of the code "ANSYS " AND RESULT

# III. Chapter III: presentation of the code ANSYS "AND RESULT

### III.1.1. Introduction

In this chapter, we present the results of the three (03) numerical simulations for a model of two dimensions (2D), so the main objective is to show the capacity of the CFD calculation code "FLUENT" to model the flow of natural convection in a material with change of phase intended to cool a solar panel

## III.2. Principles of CFD codes

CFD (Computational Fluid Dynamics) codes make it possible to numerically solve the equations governing the movements of a fluid, that is to say the equations, translate the conservation of the mass and the momentum of the fluid (Navier equations -Stokes), as well as the conservation of its enthalpy. Certain codes also make it possible to describe the transport of pollutants or chemical reactions within a fluid, the latter in fact makes it possible to meet our calculation needs.

To build a CFD model, there are several steps:

- Construction of geometry
- Construction of the mesh
- The selection of physical models: in fact, these are rarely the exact equations of Navier-Stokes which are at the origin of CFD models because solving the exact equations would be too costly in calculation time as is the case for turbulence. These are therefore approximate equations that are proposed to describe physical phenomena and all of these equations constitute a ‘model’.
- The prescription of boundary conditions.
- The selection of numerical methods to obtain an approximate solution
- Processing of results.

## III.3. Simulation procedure

The simulation process goes through 5 steps:

### III.3.1. Creating geometry

- create a geometry using ANSYS Workbench, double-click the geometry to open the module Engineering creativity "Design Modeler"

- We choose the type of 2D analysis.
- After opening the geometry creation module, we select from the “Units” menu the millimeter (mm) as the dimension unit.
- After that, we choose the plan and vision that we will work on. By clicking on the XY plane. To draw the studied geometry, click on the drawing toolbox that will allow us to create the studied geometry Geometry to add and constrain dimensions.
- In the sketch toolbox, we click on the shape of the rectangle and draw the design in the plane we have chosen, then Select the dimensions to the geometry.
- We click on We obtain the geometry of PV Cinque (5) layer as shown in the figure Fig III.

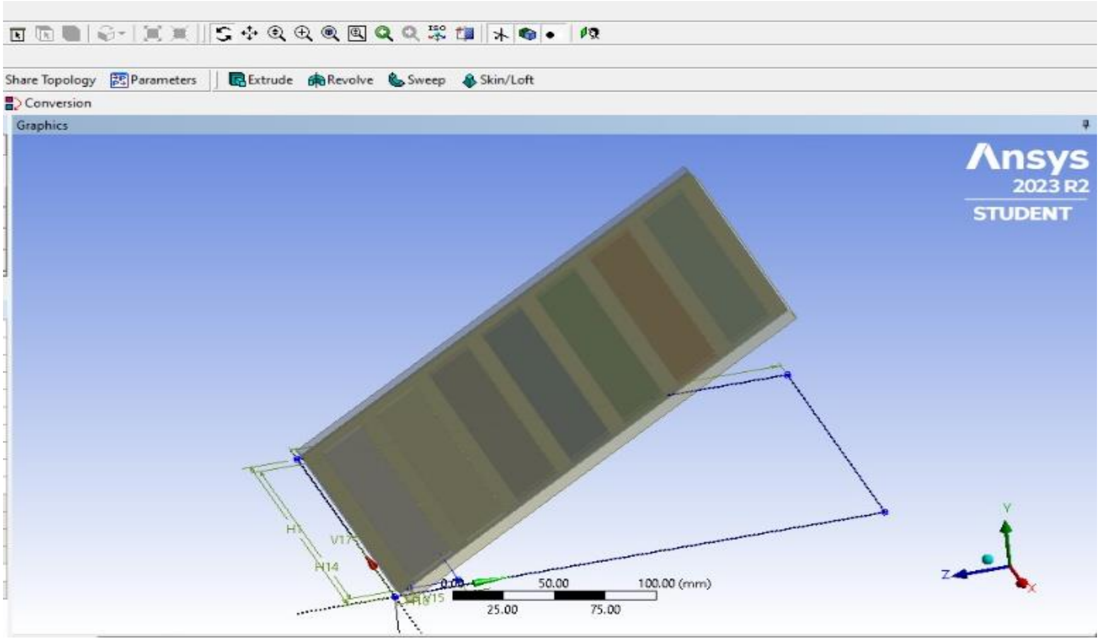


**Figure III-1:** *geometry of photovoltaic panels studied.*

Table III -1shows the thermophysical properties of the layers that make up the PV module,

**Table III-1:***Thermophysical properties of the PV module*

| | **$C_P$ $[J/Kg.k]$** | **K [w/m.k]** | **Density $[kg/m^3]$** |
|---|---|---|---|
| *Glass* | 750 | 0.7 | 2800 |
| *Eva* | 871 | 0.21 | 930 |
| *Silicon cell* | 712 | 148 | 2330 |
| *Tedlar* | 1760 | 0.23 | 1550 |

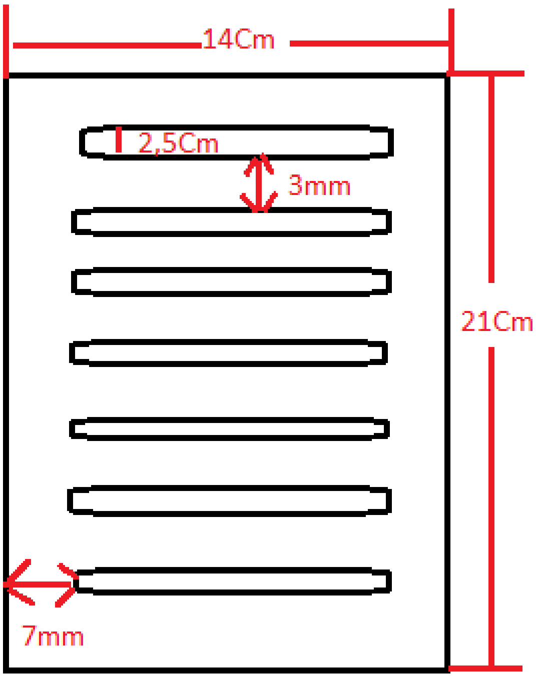


**Figure III-2:** *Dimensions of the holding tank in PCM*

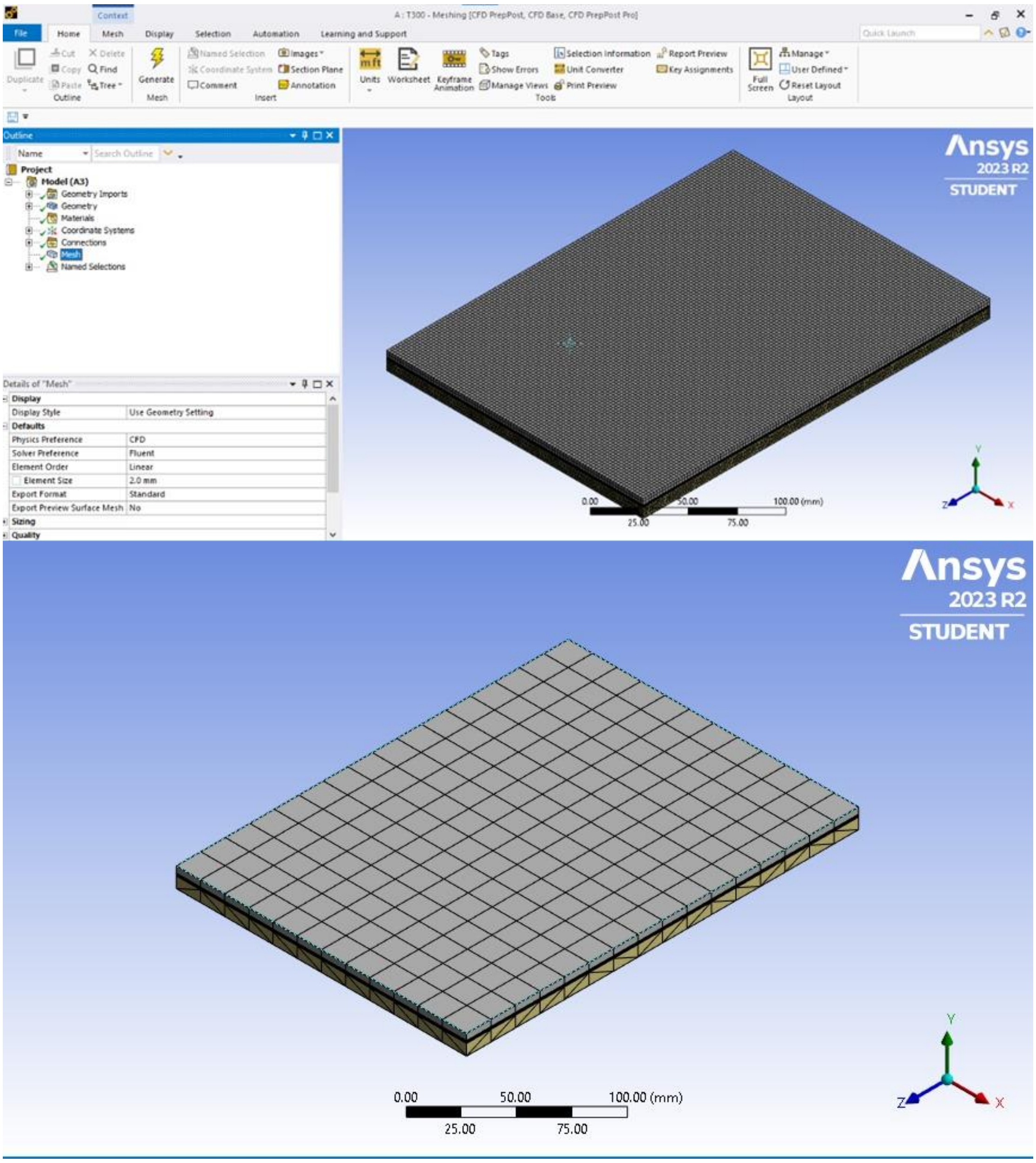
### III.3.2. The mesh

The grid in Workbench is created by double-clicking on the grid in the box Anightstand once. "Entanglement" was launched. Platform; Select part of the geometry using these two symbols:

: To select surfaces.

: To select edges.

Then we right-click on the item we want to give a nickname and choose Create Selection. "Name", then give it properties and finally we get the network as shown in the following figure:



Details of "Mesh"

| | |
|---|---|
| **Display** | |
| Display Style | Use Geometry Setting |
| **Defaults** | |
| Physics Preference | CFD |
| Solver Preference | Fluent |
| Element Order | Linear |
| ☐ Element Size | 2.0 mm |
| Export Format | Standard |
| Export Preview Surface Mesh | No |
| **Sizing** | |
| **Quality** | |

**Figure III-3:***Apply the grid to the model*

### III.3.3. Boundary conditions

The side walls (left and right) are: adiabatic (heat flow equal, Q=800;700;600). Output (bottom_wall): We assume that there is convection, (heat transfer coefficient h= 10 W m−2 K−1, T= 25°C).

## III.4. RESULTS

In this case study, the thermal performance of the PV-PCM based system is tested and presented. “ Calcium -chloride ” is used as PCM in this work operating at temperatures starting from room temperature (in our climatic region) but not exceeding 90°C. The main features of PCM are indicated in Table III - 3.

**Table III-2:** *Properties of Calcium -chloride*

| **Density $[kg/m^3]$** | **1706** |
|---|---|
| **$C_p$ $[J/Kg.k]$** | 2060 |
| **K [w/m.k]** | 1.09 |
| **Viscosity[$K_g$/(m.s)]** | 0.01 |
| **$T_L$ [K]** | 333 |
| **$T_S$ [K]** | 303 |
| **Pure Solvent Melting Heat (j/kg)** | $17*10^4$ |

We deal with two-dimensional heat transfer in a PV system assuming that radiation is present zero and with the following boundary conditions

- Heat sources include glass (top wall): Q= 1000 W/m$^2$, Q= 600 W/m$^2$, Q= 700 W/m$^2$ Q= 800 W/m$^2$
- Convection in the bottom wall (Tedlar) and PCM box with T in degrees Celsius and convection transfer coefficient h.
- The left and right (horizontal) walls are adiabatic, Q=0. We obtained 3 results shown in the following figures

- **1st case with heat source (Q= 400w/m$^2$):**

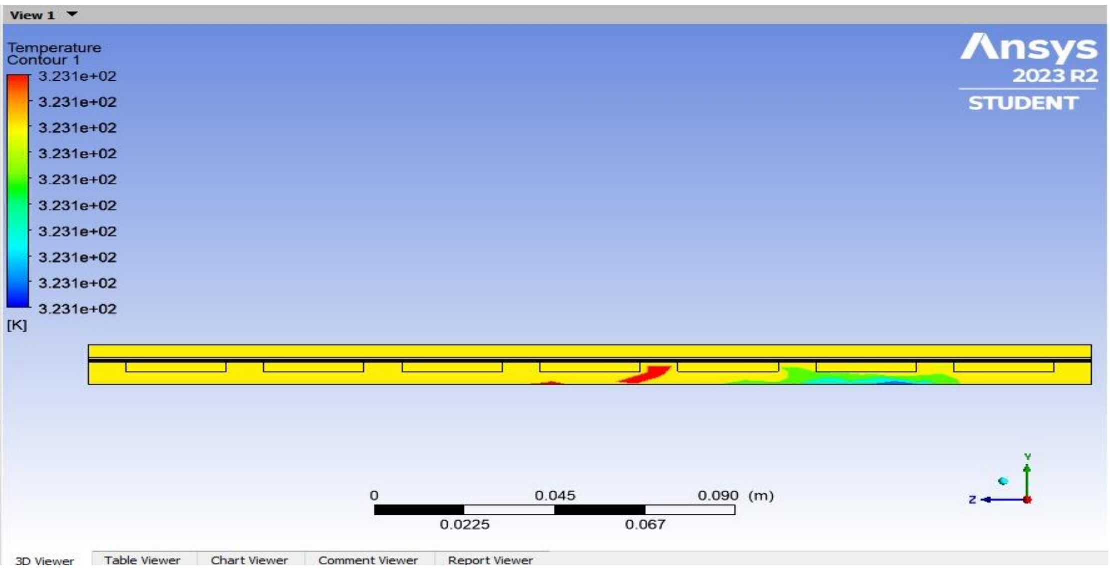


**Figure III-4:** *Temperature distribution in photovoltaic system in 1st case*

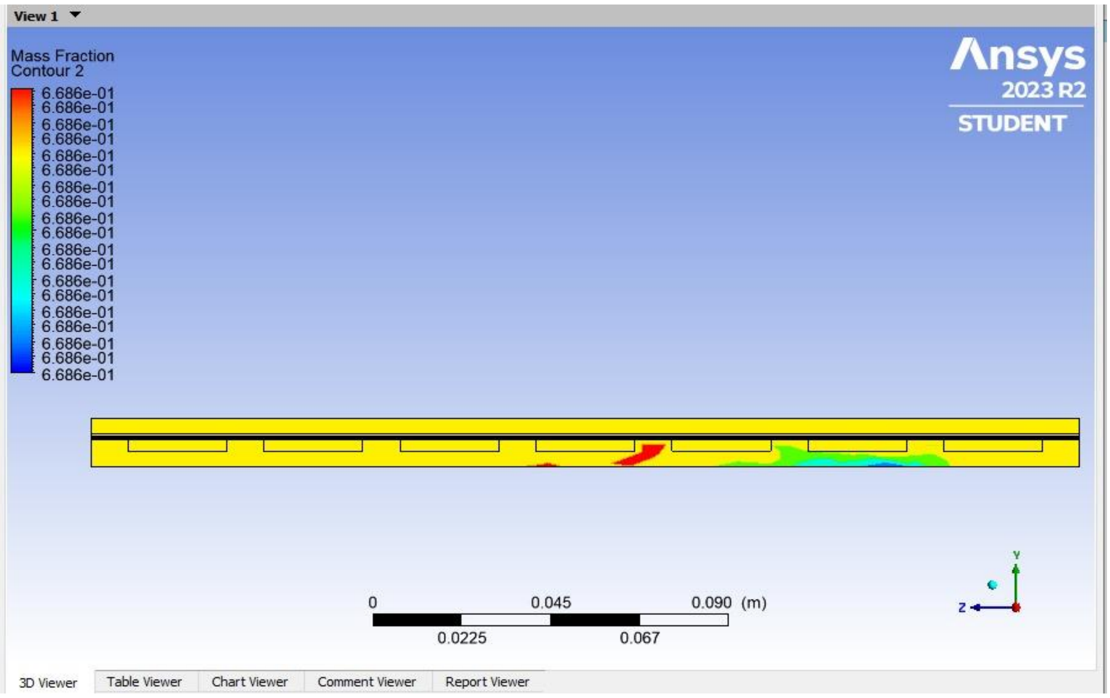


**Figure III-5:** *evolution of liquid fraction of P CM in 1st case*

- **$2^{nd}$ case with heat source (Q= 700 w/$m^2$):**

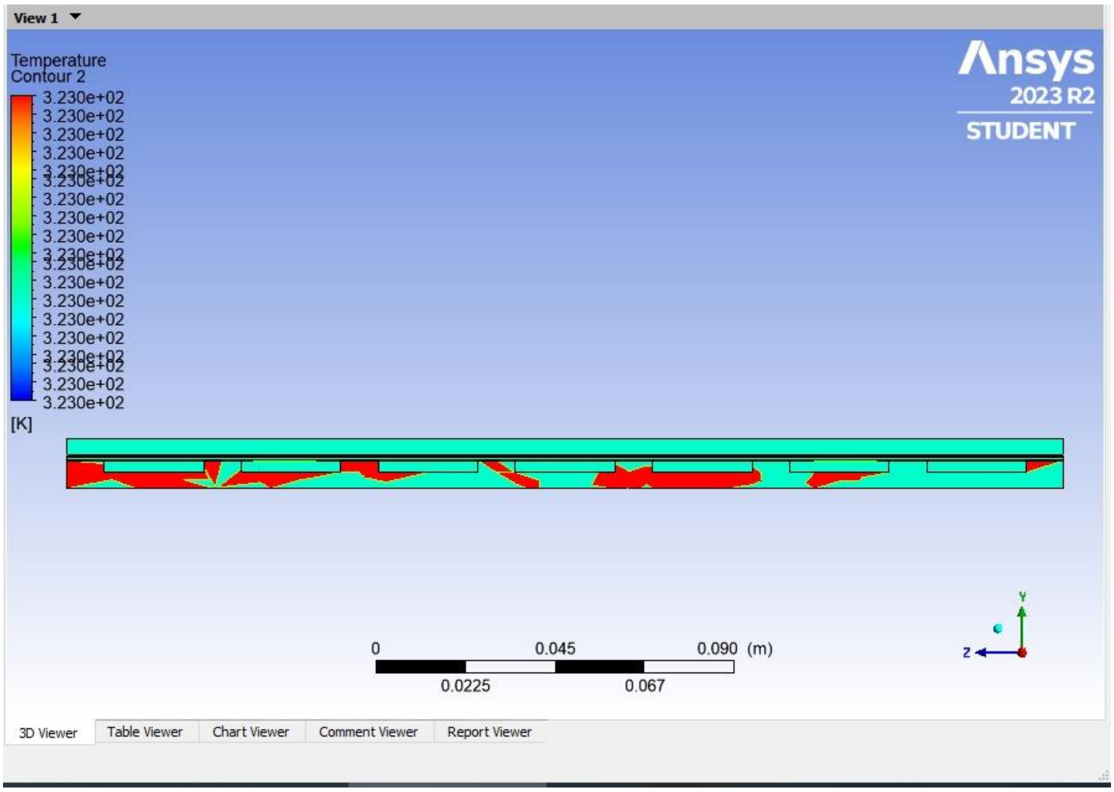


**Figure III-6:** *Temperature distribution in photovoltaic system in $2^{nd}$ case*

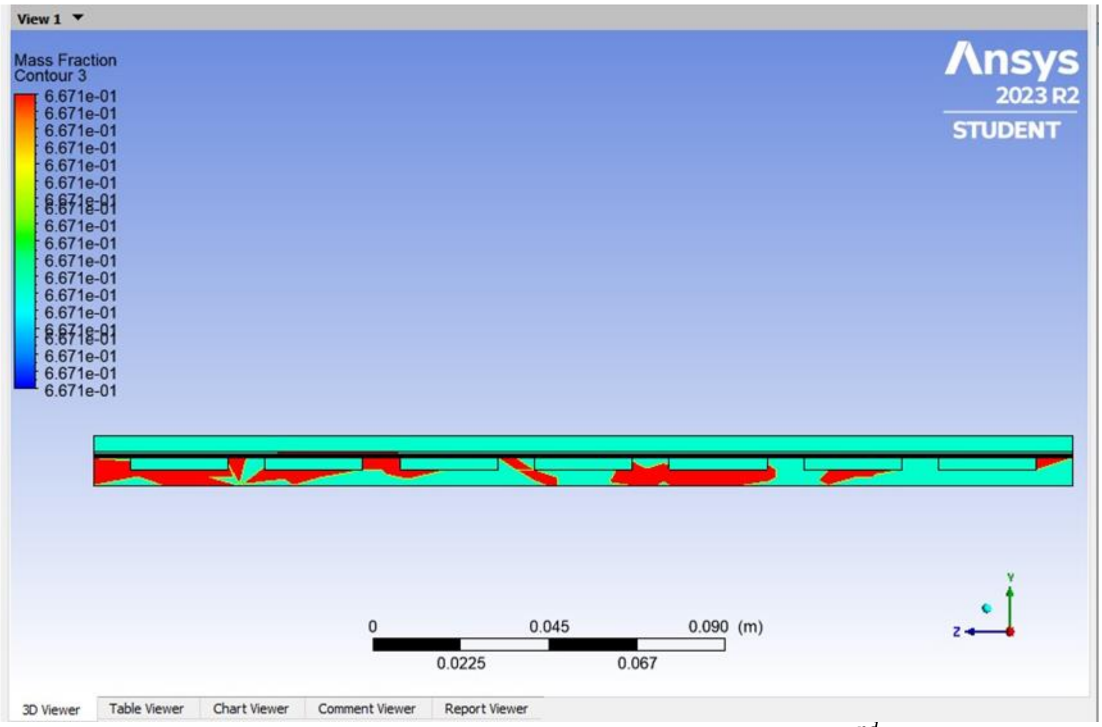


**Figure III-7:** *evolution of liquid fraction of P CM in $2^{nd}$ case*

- **3rd case with heat source(Q= 900 w/m$^2$)**

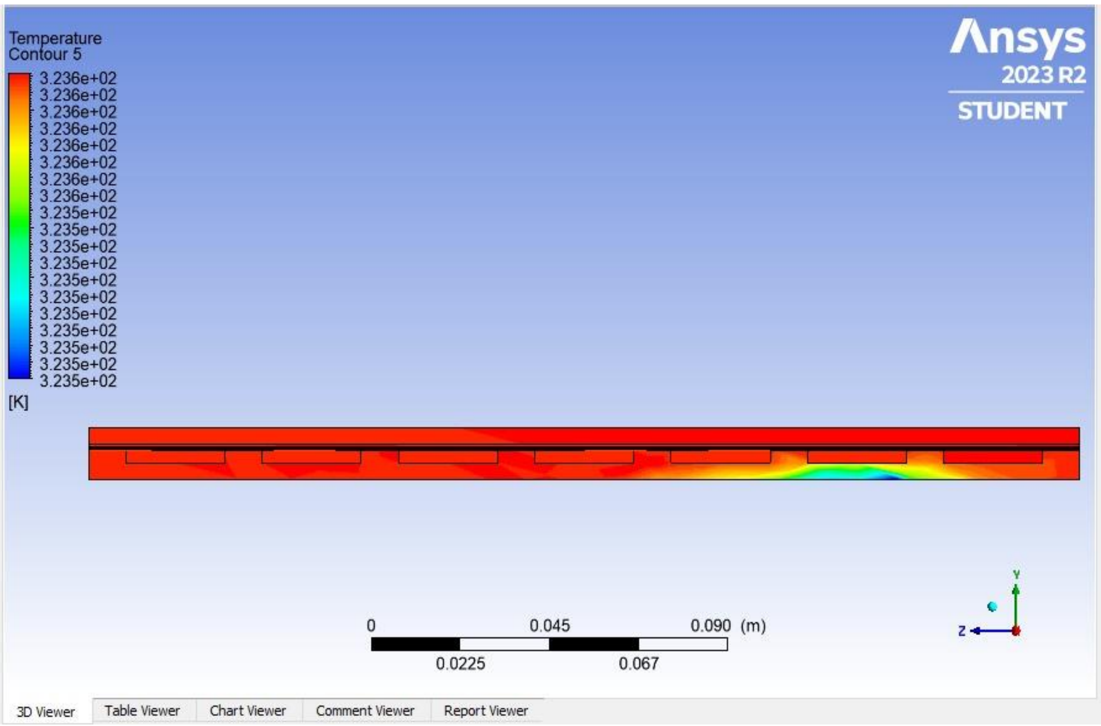


**Figure III-8:** *Temperature distribution in photovoltaic system* in 3rd case

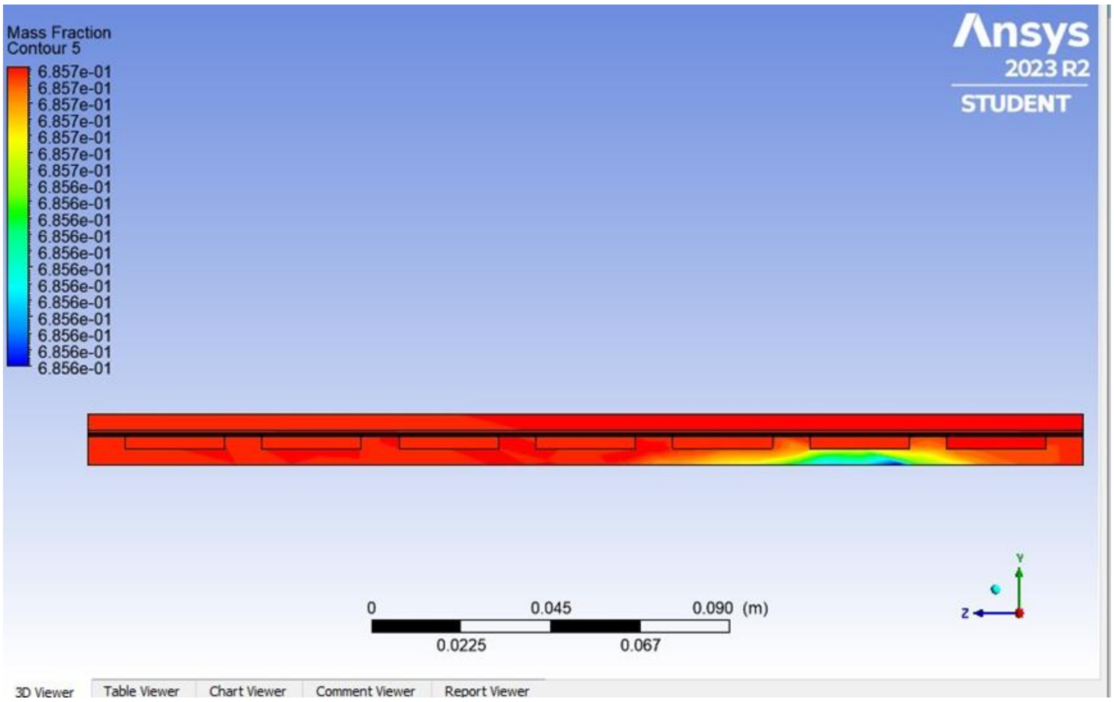


**Figure III-9:** *evolution of liquid fraction of P CM* in 3rd case

We notice from the four cases that when I change the flow, the temperature changes

### III.5. Conclusions

In this chapter, we present and discuss the results obtained from the numerical simulation Of photovoltaic panels with the aim of improving their cooling efficiency by using Calcium -chloride as PCM.

We observe during the simulation that the PV temperature increases with increasing flux Thermal (first simulation),

# General conclusion

# General conclusion

The work presented in this thesis concerns the study of numerical simulation of a photovoltaic (PV) panel, to contribute numerically to the improvement of home cooling of PV modules. Digital simulation, approached in 2D. This study is organized into three main parts, whose main conclusions are presented below:

- The first part provides generalities about solar panels
- The second part provides a bibliographic study of all research and works. Previous studies aimed to delve more deeply into this field of research.
- The third part presents the simulation process within the Lalala program and the results obtained through its discussion, and we concluded the following points:
  - The plate temperature increases after increasing the heat source or Accident or flow of heat supplied.
  - The phase change material (PCM) absorbs and stores thermal energy, thus contributing to the cooling of the PV panel. This fact favors the use of this thermal property (thermal transfer in latent heat) of the PCM to ensure that the temperature of the PV modules is maintained at an acceptable temperature for ideal operation that will increase the output power, improve the efficiency of the PV cells and protect their safety.
  - Future research work can be conducted to validate the performance of the system PV coupled to a PCM in fairly real weather conditions, as well as the optimal amount for use with the specific PCM chosen

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# Abstract:

The work presented in this thesis concerns the study of numerical simulation of a photovoltaic (PV) panel, to contribute numerically to the improvement of home cooling of PV modules. Digital simulation, approached in 2D. This study is organized into three main parts, whose main conclusions are presented below:

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Previous studies aimed to delve more deeply into this field of research.

* The third part presents the simulation process within the Lalala program and the results obtained through its discussion.

**Keyswords:** Feasibility, photovoltaic cooling system, ternary nanofluids.

**الملخص:**

يتناول العمل المقدم في هذه الأطروحة دراسة المحاكاة الرقمية للوحة الكهروضوئية، للمساهمة رقميًا في تحسين تبريد المنازل لوحدات الطاقة الكهروضوئية. محاكاة رقمية، مقاربة ثنائية الأبعاد. تم تنظيم هذه الدراسة في ثلاثة أجزاء رئيسية، والتي يتم تقديم استنتاجاتها الرئيسية أدناه:

*يقدم الجزء الأول عموميات حول الألواح الشمسية

*يقدم الجزء الثاني دراسة ببليوغرافية لجميع الأبحاث والأعمال.

هدفت الدراسات السابقة إلى الخوض بشكل أعمق في هذا المجال من البحث.

*يقدم الجزء الثالث عملية المحاكاة ضمن برنامج لالالا والنتائج التي تم الحصول عليها من خلال مناقشتها.

**الكلمات المفتاحية:** الجدوى، نظام التبريد الكهروضوئي، السوائل النانوية الثلاثية.