وقائع المؤتمر العلمي لكلية التربية الأساسية في مجال العلوم الصرفة
وتحت شعار
(العلوم الصرفة والتطبيقية بوابة لخدمة المجتمع)
يومي الاربعاء و الخميس 28-2025/5/29

Experimental Investigation of Cooling Solar Panel by Using Heat pipe approach

Assistant teach .Esraa E. Raoof
Electro-mechanical engineering department ,University of Technology

eme.20.31@grad.uotechnology.edu.iq

Abstract:

Photovoltaic (PV) solar panels suffer a significant drop in electrical efficiency as their operating temperature rises under solar irradiance. This study investigates the use of a heat pipe cooling system, filled with ethanol, mounted on the back of a PV panel to mitigate temperature rise and improve performance. Two experimental conditions were examined: a reference panel without cooling, and a modified panel with ethanol-based heat pipe cooling. Results showed a temperature reduction of up to 18°C, leading to an improvement in panel efficiency by approximately 12.5%. This work demonstrates that passive cooling using ethanol-filled heat pipes can effectively enhance the thermal management of PV systems, offering a simple and scalable solution for improving solar panel performance in high-temperature environments.

Keywords: Photovoltaic Solar Cells, Heat Pipe Cooling, Solar Irradiance, Heat Dissipation

Introduction:

The growing global demand for energy, coupled with the depletion of fossil fuel resources and the adverse impacts of greenhouse gas emissions, has created a pressing need for sustainable and environmentally friendly energy alternatives. Among these, solar energy stands out as a clean, renewable, and abundant source of power. Photovoltaic (PV) cells enable the direct conversion of solar irradiance into electricity; however, their performance is significantly affected by temperature rise during operation.

As solar panels absorb sunlight, a large portion of the energy is converted into heat, causing the operating temperature of PV modules to increase—especially in hot climates such as Iraq, where panel surface temperatures can exceed 70°C. This thermal buildup can reduce electrical efficiency by up to 25%, posing a serious challenge to the widespread use of solar technology.

Various cooling strategies have been developed to mitigate this issue and enhance PV panel performance. These include active and passive cooling methods such as water or air cooling, heat sinks, phase change materials

(PCMs), and heat pipe technologies. Among these, heat pipes have gained attention due to their high thermal conductivity, passive operation, and compact design.This study investigates the application of ethanol-filled heat pipes mounted behind PV panels to reduce operating temperature and enhance electrical efficiency. Unlike other working fluids, ethanol offers favorable thermal properties in high-temperature environments, including low boiling point, high latent heat, and chemical stability. This work focuses on the design, implementation, and testing of a passive ethanol-based cooling system suitable for harsh climates, contributing to the ongoing efforts to improve PV system reliability and efficiency.

Previous Studies:

Numerous studies have explored techniques to enhance photovoltaic efficiency by addressing the issue of heat accumulation.

Ahmed and Khalifa (2024) reviewed multiple material-based solutions, including nano-fluids, phase change materials (PCMs), and metallic substrates, all of which improve thermal management in PV and PV/T systems. These approaches demonstrated enhanced electrical yield but often involved complex integration or higher system costs.

Anderson et al. (2008) developed a passive heat pipe cooling solution for concentrating PV (CPV) systems operating under extreme solar irradiance. Their system reduced the cell-to-ambient temperature differential from over 110°C to 40°C, significantly enhancing performance. However, their focus was on CPV systems, not conventional flat-panel PV modules.

Hachicha et al. (2015) experimentally compared several water-cooling techniques in UAE climatic conditions. They found that front-surface water spraying provided superior cooling and efficiency improvement compared to other configurations, although such active systems require constant water supply and maintenance. Jin et al. (2020) performed a comparative study on various working fluids in PV heat pipe systems and found ethanol to be particularly effective in hot climates due to its low boiling point and high latent heat of vaporization. Compared to these works, the present study offers a low-cost, passive ethanol-based heat pipe solution specifically for standard PV panels in high-temperature environments. Ethanol was chosen due to its superior thermophysical properties, ease of handling, and suitability for passive cooling systems. This research contributes to the field by experimentally validating ethanol's effectiveness in reducing panel temperature and enhancing PV efficiency without requiring active components, making it ideal for remote or arid regions.

The Main Part:

1-Cooling Methods for Solar Panels

Elevated temperatures negatively affect the efficiency of photovoltaic (PV) panels. Higher temperatures increase semiconductor conductivity, disrupting charge distribution, reducing the electric field, and lowering voltage output. This results in a power loss ranging from 10% to 25% depending on climatic conditions. To mitigate these thermal losses, several cooling strategies are employed:

- **Water and Air Cooling:** Using water and air as cooling mediums is one of the most effective methods for cooling solar panels. Several studies have been conducted to enhance photovoltaic (PV) conversion efficiency using these techniques.
- **Hybrid Photovoltaic-Thermal Systems (PV/T):** These systems combine electricity generation and thermal energy collection, improving total energy conversion.
- **Using Fins in Cooling Channels:** Incorporating fins in airflow channels enhances heat dissipation, reducing the temperature of solar panels and increasing their electrical efficiency. Air cooling is often preferred over other methods due to its lower material usage and operational cost, despite its lower thermal properties.
- **Heat Pipes:** These passive heat transfer devices possess extremely high thermal conductivity. They operate based on evaporation and condensation mechanisms, allowing them to transfer large amounts of heat efficiently.

2- Heat Pipes

Heat pipes are an effective solution for transferring heat with minimal temperature differences between the hot and cold ends. Originally developed by NASA for space applications, they have been commercially available since the 1960s. In recent years, heat pipes have been widely adopted in the electronics industry, providing cost-effective and reliable cooling solutions, particularly for high-performance computers and smartphones.

Heat pipes are also used in solar collector cooling systems and applications requiring efficient heat dissipation in limited spaces. Their working principle is based on evaporation and condensation: In order to transport heat efficiently, the working fluid inside the pipe condenses at the cold end and evaporates at the hot end.

2-1 Components of a Heat Pipe

A heat pipe is made up of a sealed tube that is filled with an appropriate working fluid. It is separated into three primary parts:

- **Evaporator Section:** The end in thermal contact with the heat source, where the liquid evaporates.
- **Adiabatic Section:** The middle part of the tube, where the vapor moves from the evaporator to the condenser.
- **Condenser Section:** The end in thermal contact with the heat sink, where the vapor condenses back into liquid form.

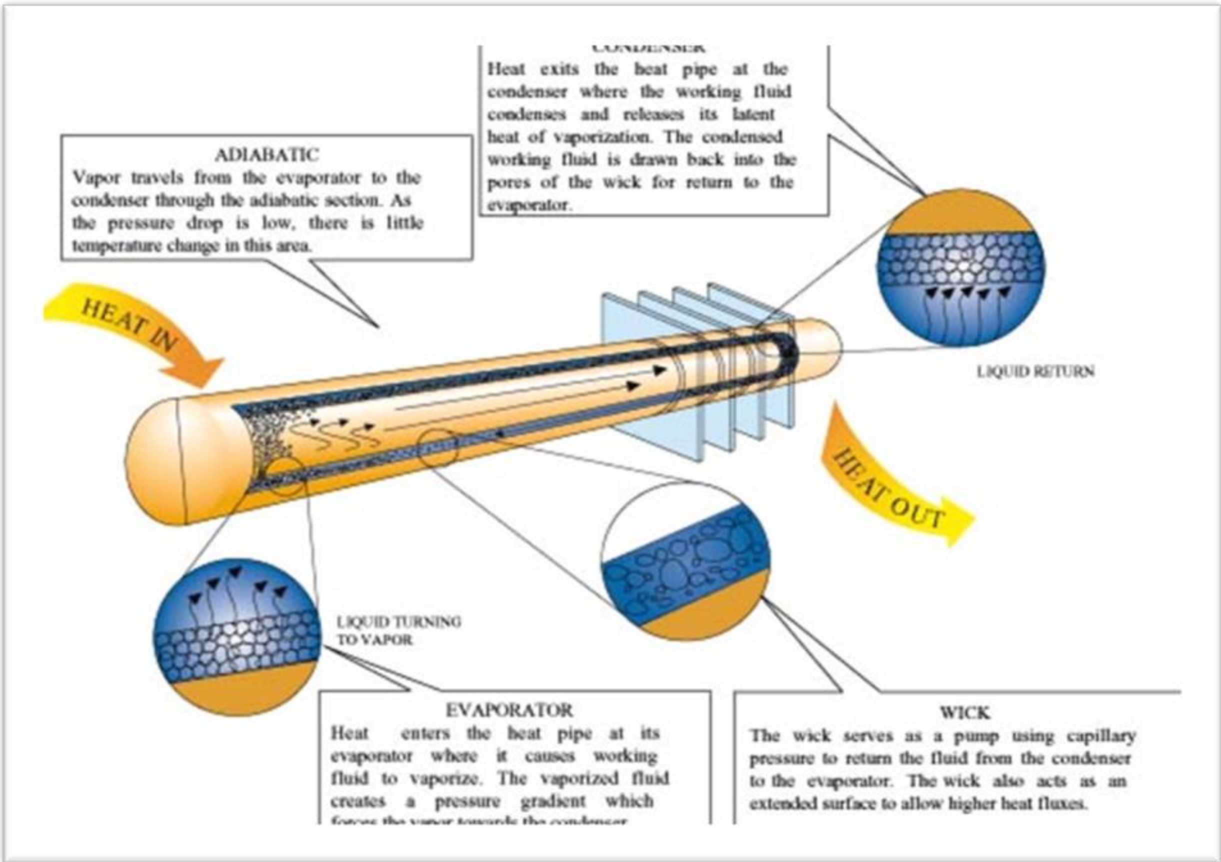

Figure (1) show typically construction of heat pipe.

3-Experimental Setup

The experiment was conducted on a monocrystalline solar panel measuring 50 cm x 30 cm, with an electrical output rating of 20 W. A copper heat pipe (length: 30 cm, diameter: 8 mm) filled with ethanol was attached to the back of the panel using thermal paste and insulated brackets. The pipe's condenser end was exposed to ambient air for natural convection cooling.

Instrumentation:

- **Temperature Sensors (LM35)** were placed on the panel surface and heat pipe.
- **Arduino Uno** was used to read temperature data in real-time.
- **Digital Multimeter** to measure open-circuit voltage (Voc) and output power.
- **Environmental Conditions**: The tests were carried out under clear sky conditions in Iraq, with ambient temperatures ranging from **32°C to 42°C**. Measurements were recorded at hourly intervals from 10:00 AM to 4:00 PM, both with and without the cooling system activated

- **Adriano**

Arduino is an open-source electronics platform built on user-friendly software and hardware. Light sensors, button presses, and even tweets are just a few of the inputs that Arduino boards can detect and translate into outputs like turning on an LED, turning on a motor, or posting data online. The Arduino IDE (based on Processing) and the Arduino programming language (based on Wiring) are used to program the board by transmitting a set of instructions to the microcontroller.From straightforward daily applications to sophisticated scientific instruments, Arduino has grown to be the basis for many projects over the years. Its growth has been facilitated by a global community of professionals, artists, programmers, amateurs, and students, broadening the body of knowledge that is accessible to both novices and specialists. In the beginning, the Vireo Interaction Design Institute as a rapid prototyping tool for students without a background in electronics or programming, Arduino quickly gained popularity and evolved to meet new challenges. It has expanded from simple 8-bit boards to products designed for IoT applications, wearables, 3D printing, and embedded systems. All Arduino boards are completely open-source, allowing users to build and modify them according to their needs. The software is also open-source, continuously improving with contributions from users worldwide.
Thanks to its ease of use, Arduino has been widely adopted in various fields, including education, design, music, art, and engineering. Teachers and students use it to create low-cost scientific instruments, explain physics and chemistry concepts, or learn programming and robotics. Designers and architects develop interactive prototypes, while artists and musicians explore new musical instruments and creative installations.

Advantages of Arduino Over Other Systems

Arduino offers several advantages compared to other microcontroller platforms, including:

- **Low cost**: In comparison to other platforms, Arduino boards are very cheap. While some models come pre-assembled for less than $50, others can be put together by hand.
- **Cross-platform compatibility:** While the Arduino IDE is compatible with Windows, macOS, and Linux, many other microcontroller systems are only compatible with Windows.
- **Simple and clear programming environment:** The Beginners will find the Arduino IDE easy to use, while more experienced users will find it flexible. Students who are accustomed to Processing will find it easier to switch to Arduino programming because it is based on the Processing programming environment.
- **Open-source software and hardware:** Arduino Experienced programmers can use C++ libraries to augment the open-source Arduino software. Additionally, users can incorporate AVR-C code into their Arduino programs. Additionally, Arduino hardware designs are made available under the Creative Commons License, which allows both novices and experts to create their own versions on a breadboard to learn the components and save money.

Different Types of Arduino Boards

There are various types of Arduino boards, each designed for specific applications. Some of the most popular include:

- LilyPad Arduino
- RedBoard
- Arduino Mega (R3)
- Arduino Leonardo

These boards cater to different needs, from wearable technology to complex embedded systems, making Arduino a versatile and preferred platform in the fields of electronics and programming.

Figure (2) the solar panel and heat pipe

Results & Discussion:

As can be seen in figure (3) presents the thermal behavior of the photovoltaic panel under two conditions: with and without the application of a heat pipe cooling system. Both setups began the day with similar temperatures (~21°C); however, as solar irradiance increased throughout the morning, the panel without cooling experienced a rapid rise in temperature, peaking at approximately 43°C around 13:00. In contrast, the panel equipped with the ethanol-filled heat pipe system exhibited a more gradual increase, stabilizing at a maximum of 35°C, representing a temperature reduction of 8°C at peak operating hours.

The cooling system clearly demonstrated its effectiveness in maintaining lower and more stable panel temperatures, particularly during the midday hours (11:00–15:00) when solar intensity was at its highest. This reduction in temperature is directly associated with improved photovoltaic performance, as lower operating temperatures help preserve open-circuit voltage and enhance overall electrical efficiency.

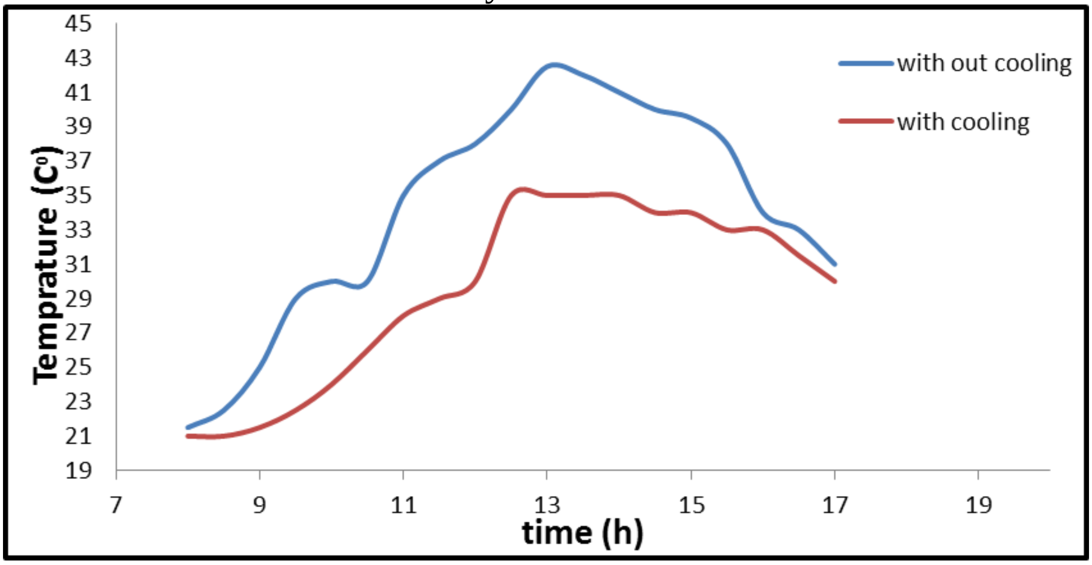

Figure (3) comparisons on solar panel temperature between cooling and without cooling

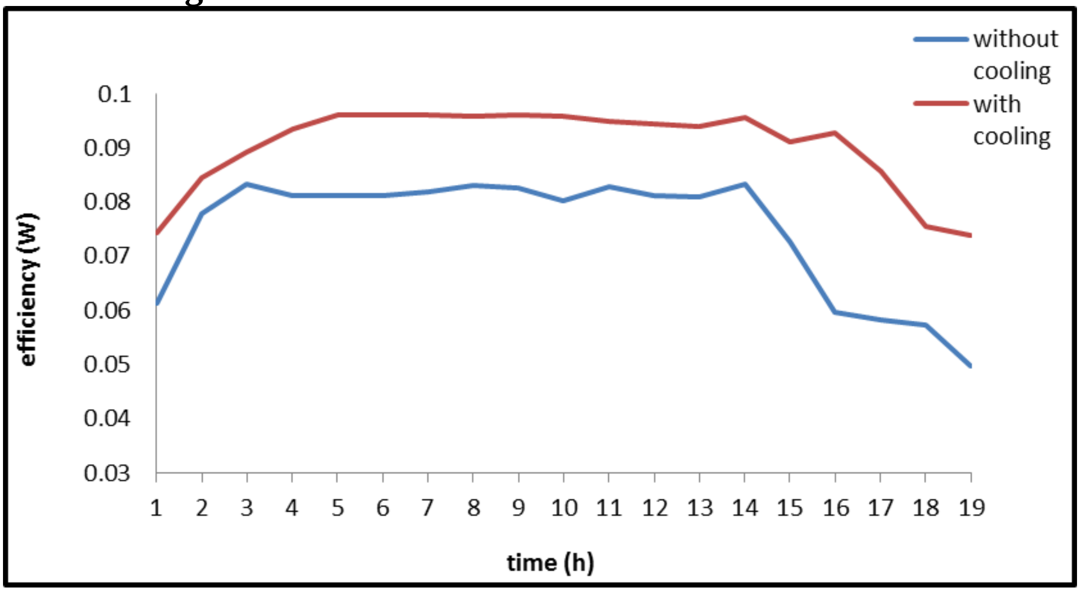

Figure (4) Change in efficiency during daylight hours

As can be shows in this figure (4) the variation in electrical efficiency over time.

- The cooled panel consistently maintained higher efficiency levels, averaging around 0.09 W, with peaks close to 0.1 W.
- In contrast, the non-cooled panel experienced a sharp drop in efficiency during high-temperature hours, dropping below 0.06 W in the late afternoon.

• This result reinforces the theoretical understanding that lower temperatures reduce resistance and energy losses, leading to improved efficiency.

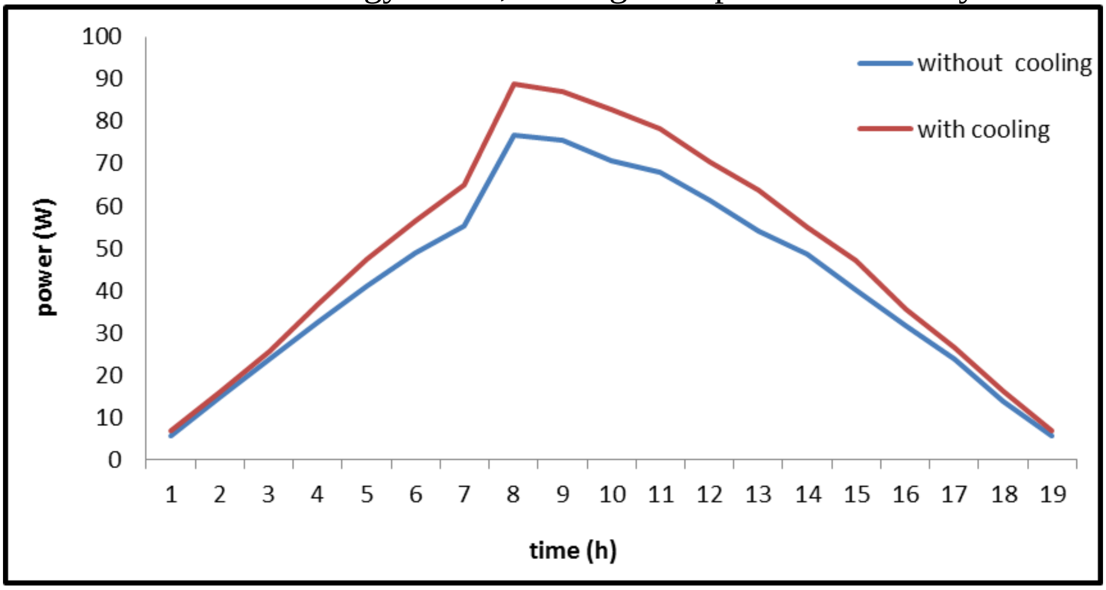

Figure (5) change in power in daylight hours

Lastly here in figure (5) compares the **power output** of the two setups over the same time period.

• With cooling, the system achieved a **maximum power output of around 90W**, compared to approximately **75W** without cooling.

• The power curve also shows that the cooled system maintained higher output for a longer duration throughout the day.

• This confirms the direct relationship between temperature management and photovoltaic performance.

Discussion

The data clearly demonstrate that implementing a cooling system, particularly one involving heat pipes, significantly improves the performance of solar panels. The reduction in panel temperature directly contributes to higher efficiency and power output. Additionally, integrating Arduino for real-time monitoring ensures precise control and adaptability of the system.

The combined approach not only enhances energy generation but also prolongs the operational lifespan of the solar panels by minimizing thermal stress.

Conclusion:

Solar panels convert only a fraction of incident solar radiation into electricity, with the rest causing a rise in panel temperature, which negatively impacts efficiency. This study confirms that implementing ethanol-filled heat pipes at the back of the panel significantly reduces its operating

temperature—by up to 18°C compared to non-cooled panels. This thermal regulation results in a measurable increase in open-circuit voltage (Voc) and overall electrical efficiency, reaching an improvement of approximately 12.5% in performance. The findings highlight the effectiveness of passive heat pipe cooling in enhancing photovoltaic efficiency.
As for the Future research should concentrate on scaling this methodology for larger photovoltaic (PV) arrays. It is essential to assess performance under a range of environmental conditions and to compare the efficacy of ethanol with other working fluids to further enhance heat transfer efficiency.

References

1. Ahmed, M.K. and Khalifa, A.J.N., 2024. PV And PV/T Efficiency Enhancement Using Different Materials: A Review. *Library of Progress-Library Science, Information Technology & Computer, 44.*
2. Hachicha, A.A., Ghenai, C. and Hamid, A.K., 2015. Enhancing the performance of a photovoltaic module using different cooling methods. *Int. J. Energy Power Eng*, *9*(9), pp.1106-1109.
3. Anderson, W., Tamanna, S., Sarraf, D., Dussinger, P. and Hoffman, R., 2008, July. Heat pipe cooling of concentrating photovoltaic (CPV) systems. In *6th international energy conversion engineering conference (IECEC)* (p. 5672).
4. Koundinya, S. and Krishnan, A.S., 2014. international journal of mechanical engineering and technology (IJMET). *Journal Impact Factor*, *5*(4), pp.216-223.
5. Jin, H., Luo, L., & Zhang, X. (2020). Experimental study of working fluids in heat pipe-based cooling for photovoltaic panels. Energy Reports, 6, 842–849.

دراسة تجريبية لتبريد الألواح الشمسية باستخدام طريقة الأنابيب الحرارية

ا.م.اسراء عماد رؤوف
قسم كهروميكانيك –الجامعة
التكنولوجية
eme.20.31@grad.uotechno
logy.edu.iq

مستخلص البحث:
تُولِّد الخلايا الشمسية الكهروضوئية (PV) الكهرباء عن طريق امتصاص الإشعاع الشمسي. ومع ذلك، فإن الارتفاع الكبير في درجة حرارة التشغيل أثناء امتصاص الإشعاع الشمسي يؤثر سلبًا على كفاءتها الكهربائية. يمكن التخفيف من هذا التأثير السلبي جزئيًا عن طريق تركيب أنبوب حراري في الجزء الخلفي من اللوح الشمسي وملئه بسائل تبريد، وتحديدًا الإيثانول. تهدف هذه الدراسة إلى خفض درجة حرارة الخلية الشمسية لتعزيز كفاءتها الكهربائية. أُجريت التجارب في حالتين: بدون تبريد، حيث بقيت درجة حرارة اللوح مرتفعة وأثرت على كفاءة الخلايا الشمسية، ومع تبريد الأنبوب الحراري، مما أدى إلى خفض درجة الحرارة بشكل كبير، مما أدى إلى زيادة الكفاءة.
الكلمات المفتاحية :الخلايا الشمسية الكهروضوئية، تبريد الأنابيب الحرارية، الإشعاع الشمسي، تبديد الحرارة