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Enhancing Solar Panel Efficiency: A Comparative Study of PV Systems with and without Phase Change Materials (PCM)

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ABSTRACT

The use of thermal storage materials, like as Phase Change Materials (PCM), in PV panels has been studied to magnification the performance efficiency of the panels by alleviate the negative effects of temperature rise on their performance. (PCMs) recover a large heat during transformation from solid to liquid phase because of having a large latent heat which making it full of promise for thermal energy storage applications.

This work made a comparison between the performance efficiency of solar panels with and without using PCM, highlighting how thermal storage materials improve overall performance. The efficiency of PV panels mainly related to operating temperature which decreases as the surface temperature increases. This study discuss use of Phase change Material (PCM) based cooling to reduce the rise of temperature of PV panels and enhance their efficiency. The primary parameters studied and measured were the surface temperature of the PV panel and its efficiency. The result of experiments demonstrate that the use of PCM cooling system led to efficiency improvements of 4.2%, 4.1%, and 3.9% in different conditions. The corresponding maximum temperature decreasing achieved were 14.1°C, 12.1°C, and 9.5°C, respectively. These findings has proven that the use of PCM cooling systems to impact the performance of PV panels by effectively managing temperature has contributed to improving and increase efficiency of PV panels.

Keywords: PV panel, Thermal storage materials, PCM cooling system, performance of PV panel, solar energy

1.INTRODUCTON

The efficiency of photovoltaic (PV) panels depends largely on their operating conditions mainly the temperature. When solar panels absorb solar radiation, they convert apart of it into electrical power, but they also absorb and retain unlimited amount of heat. This heat in turn cause an increase in the surface temperature of the panels, which in turn reduce efficiency of PV panel. Typically, the efficiency of PV panels decreases by approximately 0.4% to 0.5% per each increase by one degree Celsius in temperature beyond the reference operating temperature, which is generally around 25°C [1] . This temperature effected decrease in performance is a major interest in regions and positions with high solar irradiance, and effectively thermal storage management systems are urgent for maintaining panel performance.

One of the optimistic prospect full of promise solution to address this issue is that by using of Phase Change Materials (PCMs). PCMs are materials that absorb or release large latent heat when they transit from solid to liquid phase, allowing them to store and recover large amounts of heat and thermal energy during the phase transition process [2]. This progress makes PCMs highly preferable for using in thermal and heat management systems, as they can control and regulate the temperature, preventing of PV panels from heating rise while maintaining their efficiency. When integrated with PV panel systems, PCMs can absorb excess heat from the PV panels as they transit melt from solid phase to liquid phase and release absorbed stored heat during process of cooling, standing the temperature of the PV panel within an optimal working range for energy generation [3]

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Researcher has proven that using of PCMs as cooling and management materials in PV panels can significantly enhance their performance. By preventing overheating cause's excessive temperature rises, PCMs help keeping the PV panel temperature in the range of its optimal operating temperature, therefore reduce the efficiency drop related to overheating [4]. Studies showed that the integration of PCM-based cooling systems can make efficiency enhancement of up to 6-7%, depending on the kind of PCM used and the region environmental conditions [5]. Furthermore, the use of PCMs can longitude the operational lifespan of PV panels by mitigating the heat stresses that lead to degradation over time [6].

Moreover, the integration of PCMs in PV systems is not specific to conventional solid-liquid phase change materials. New advancements have discovered the use of multi composite PCMs, which benefit from and combine the thermal properties of different materials to improve the thermal conductivity and storage ability of the PCM [7]. For instance, the combination and integration of PCM with metal foams or graphite can increase the heat transfer rate, making it more efficient in regulating and keeping the temperature of the PV panels around the operating temperature [8].

As the demand for sustainable energy continues to rise, maximizing the efficiency of solar energy systems has become major issue. The combination of PCMs in PV systems offers an optimistic prospect promising solution to issue of temperature-related efficiency drop, making solar energy generation more reliable and efficient, especially in high-temperature region [9].The renewable energy is great substitute for ordinary fossil fuel [10].

2.EXPERMENTAL

The described experimental setup involved the use of two identical PV panel with 30W monocrystalline and 19.5V optimal operating voltage, 22.9V open-circuit voltage, and 1.70A short-circuit current. The panels were part of a solar-thermal system that associated with phase change material (PCM) – specifically paraffin wax to improve the system's heat storage and release capabilities.. The goal of the experiment was to assess how the inclusion of PCM, in terms of temperature control, efficiency, and thermal storage.

Panel dimensions: 650 mm x 350 mm x 25 mm. The PCM container was constructed from wood and sealed with RTV silicone to prevent leakage during the melting phase .Thermo-physical properties of PCM (paraffin wax) were outlined in Table 1

Table 1 physical properties of PCM

Melting temperature of the PCM	54.32 °C
Latent heat of fusion	184.48 kJ/kg
Density of the PCM (liquid phase)	775 kg/m
Density of the PCM (solid phase)	833.60 kg/m'
Specific heat of the PCM (solid phase)	2.384 kJ/kg °C
Specific heat of the PCM (liquid phase)	2.44k J/kg °C
Thermal Conductivity	0.15 W/m°K
Viscosity	6.3 X10-3
Kinamatic Viscosity	8.31 X10-5 m/sec
Prandtl Number	1001.23
Thermal Expansion Coefficient	7.14 X 10^{-349}

The setup was tested in Albalidiat, Baghdad, Iraq, during three different cases on 20th April, 16th June and 8th July 2024

Thermal data was collected using calibrated thermocouples placed on the PV panel surface and inside the thermal storage materials.First Case: 20th April, second Case: 16th June, third Case: 8th July 2024, Thermocouples measured temperatures with an accuracy of ±0.01%.

Solar irradiation was measured with a meter having an accuracy of ±0.7%.Data was recorded for irradiation and temperature variations over the course of the experiments.

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During the thermal charge phase, the PANEL with PCM released heat more effectively than the one without PCM. This is attributed to the thermal conductivity and specific heat capacity of the PCM material.the system with PCM provided a heat storage more than 4.5 hours

Efficiency increased by 4.5% with PCM compared to the panel without storage material.

During the charge phase (after 12:30 PM), the PV-PCM showed an increase in efficiency of around 4% compared to the panel without storage material.

The cooling system of the PCM, effectively distributing the heat inside the wax and reducing the time it took for the PCM to melt. This led to faster thermal charging times and improved overall system performance.

The PV-PCM system used in the experiment consisted of one PV panel coupled with a PCM-based cooling system, while the other panel served as the reference system (without PCM cooling). The PCM system was designed to cool the PV panel by absorbing the heat via the phase change process.

The height of the PCM container was 40 mm, chosen based on the mass of the PCM and the dimensions of the PV panel.

The mass of the PCM was calculated to absorb all the PV panel heat available throughout the day, storing it as latent heat. This ensured that the temperature of the PV panel remained near the phase change temperature of the PCM, helping to maintain the panel's temperature close to the optimum value, K-type thermocouples were used to measure the temperature of the PCM inside the container.

3. RESULTS AND DISCUSSION

The experiments were conducted three times, and the average results were used for analysis. The performance of the conventional PV panel and the PV-PCM system were compared in terms of efficiency, which was calculated using the formulas provided.

3.1. The PCM-based cooling system helped to maintain the temperature of the PV panel closer to the optimum operating temperature (25°C). By storing the heat as latent energy, the PCM absorbed excess heat during the day and kept the panel temperature near the phase change temperature of the PCM which shown in the figures 1-3 .

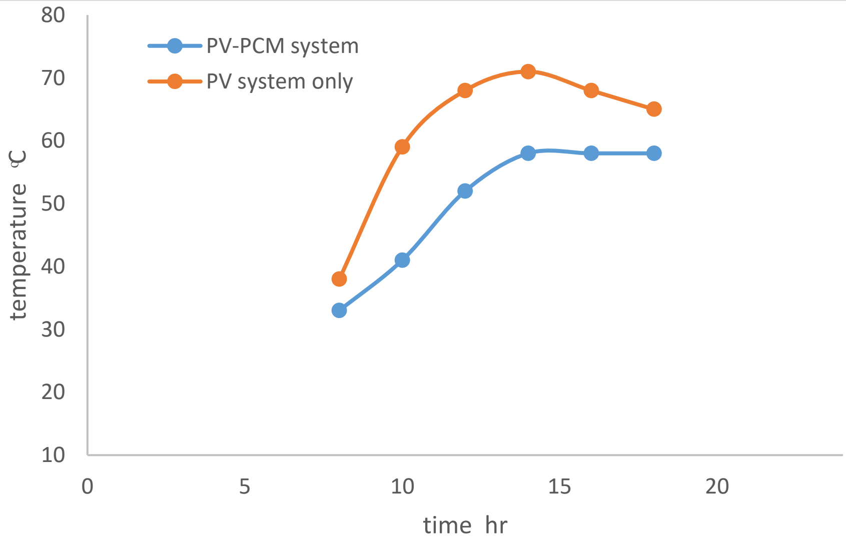

Figure 1 temperature of PV-PCM system and PV only for case 1

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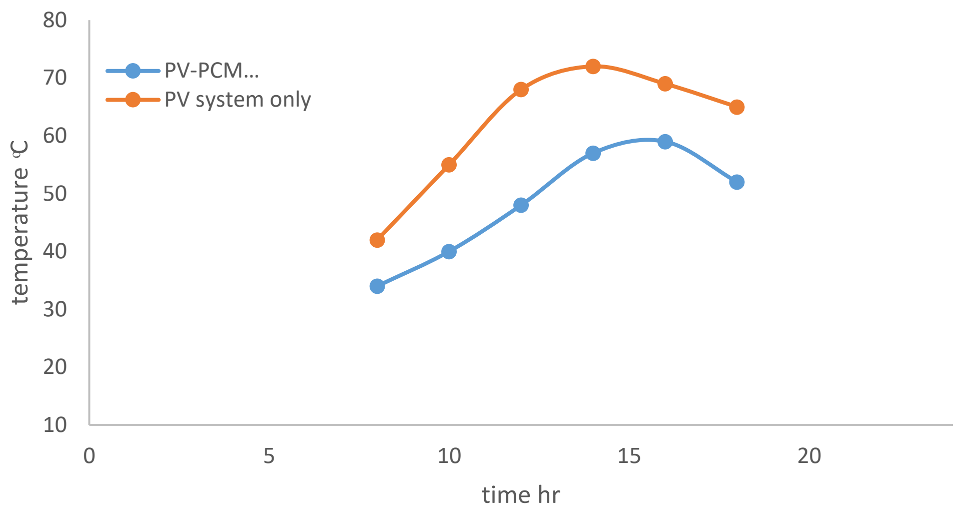

Figure 2 temperature of PV-PCM system and PV only for case 2

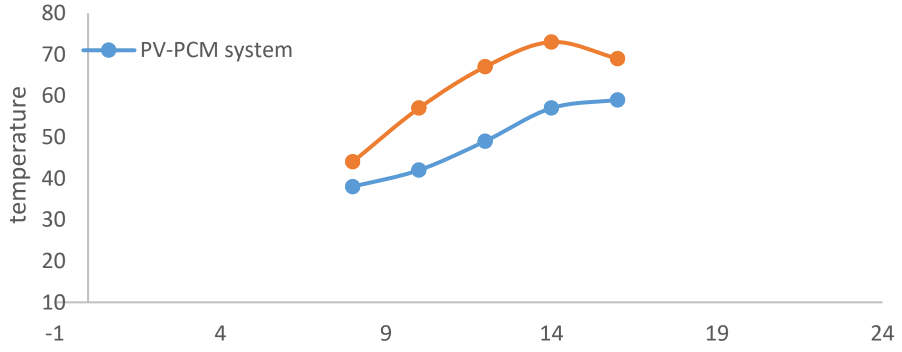

Figure 3 temperature of PV-PCM system and PV only for case 3

3.2. When the PCM system was employed, it helped improve the performance of the PV panel by preventing it from overheating, which typically reduces the efficiency of PV panels. The PCM-augmented system showed an increase by 4-5% improvement efficiency to the conventional PV systems in the figures 4-6. The percentage enhancement in efficiency varied depending on the solar irradiation and temperature conditions, but it was consistently higher than the conventional system, as the PCM helped to regulate the panel's temperature.

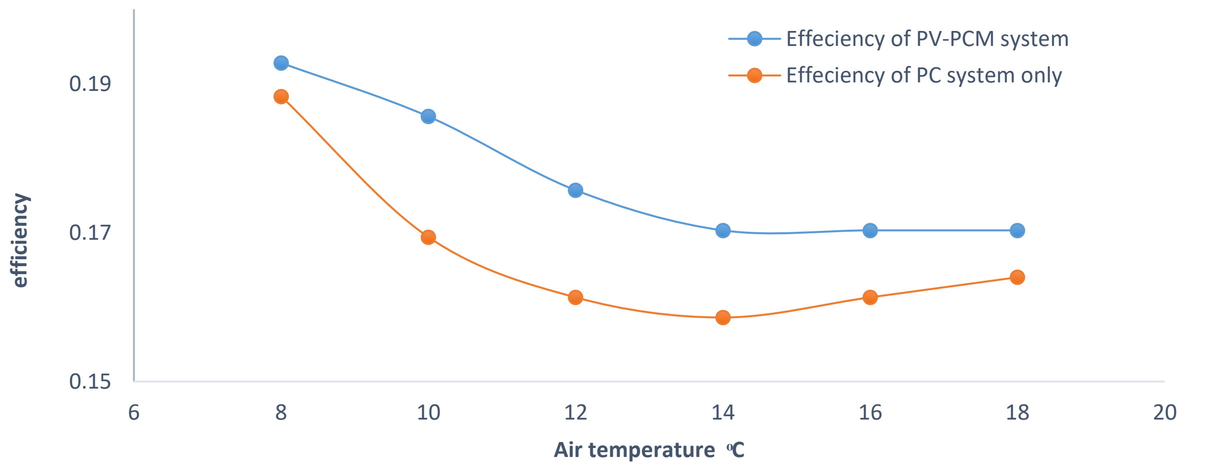

Fig 4 effect of air temperature on panel efficiency with and witout PCM for case 1

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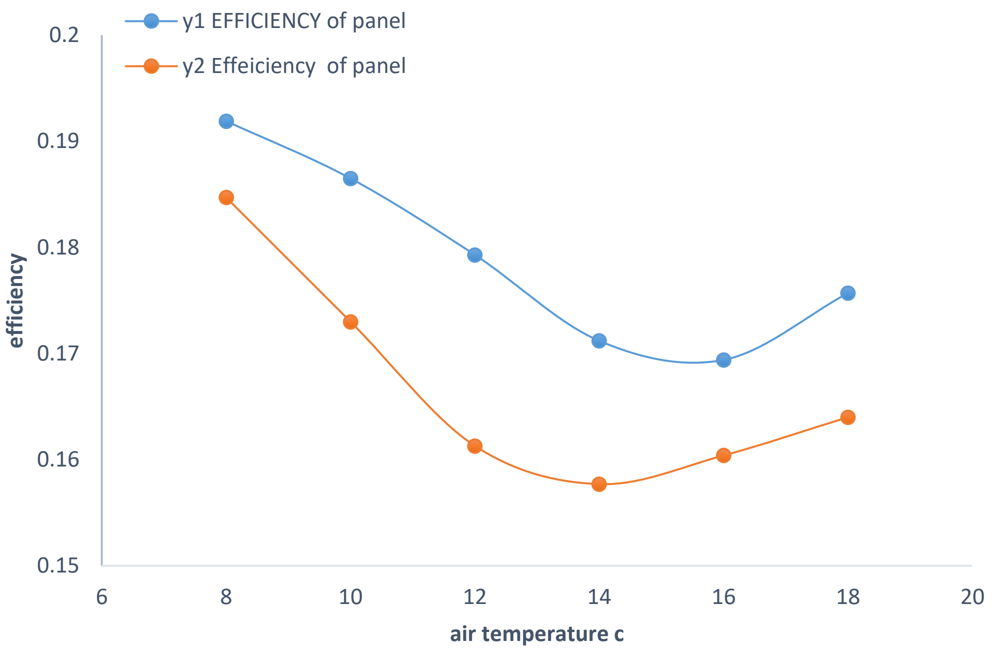

Figure 5 effect of air temperature on panel efficiency with and witout PCM for case 2

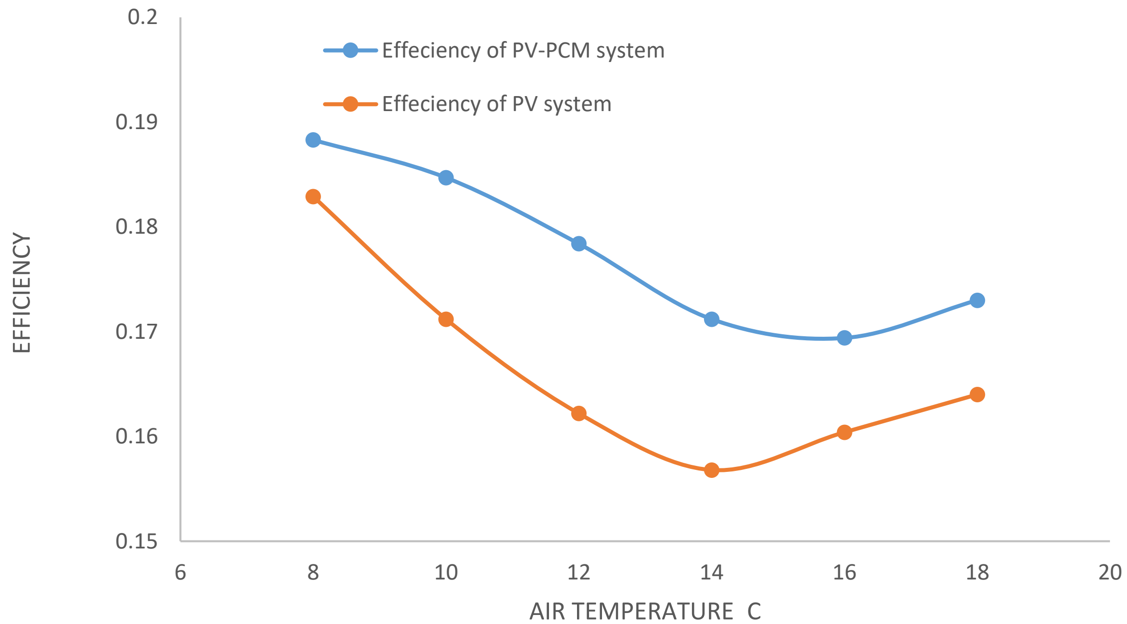

Fig 6 effect of air temperature on panel efficiency with and witout PCM for case 3

3.3. The use of PCM ensured that the heat collected by the PV panel throughout the day was stored and later released, preventing temperature fluctuations that could impact the panel's efficiency. This ability to store heat as latent energy was key to maintaining a more consistent temperature in the PV panel, allowing it to operate more efficiently.

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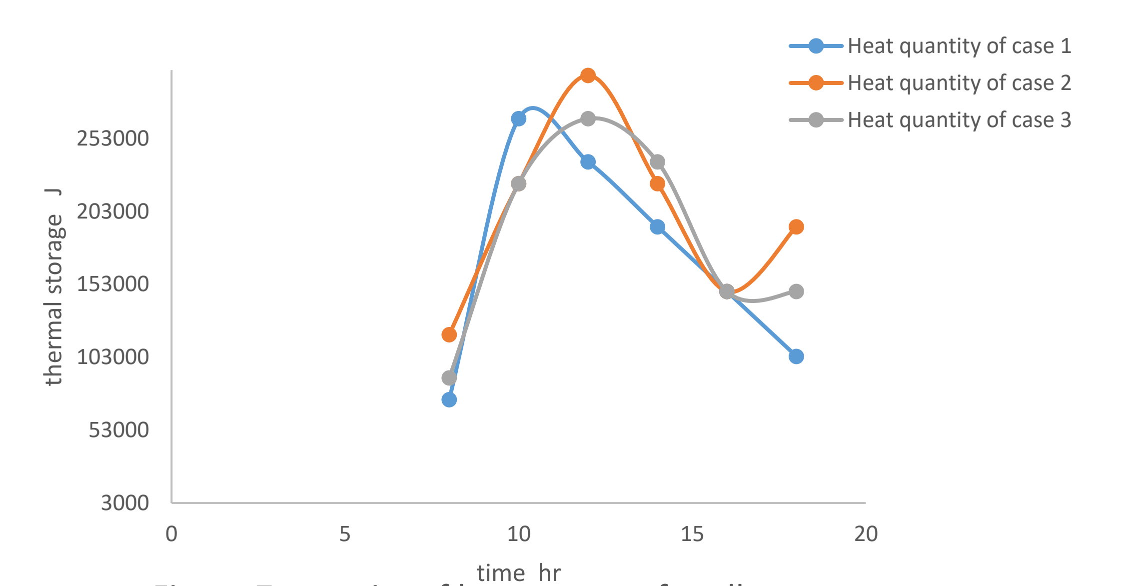

Figure 7 quantity of heat storage for all cases

4.CONCLUSION:

The experimental results highlight that the integrating PCM as thermal storage in pv systems enhances the performance, enhances performance by regulating panel temperature and minimizing efficiency losses. While the charging phase may see efficiency gains, especially with high thermal conductivity materials, the overall impact remains positive.

The experimental results demonstrate that the integration of a PCM cooling system significantly improvement the efficiency of PV panels by maintaining optimal operating temperatures and mitigating the temperature-related losses that typically diminish the performance of conventional PV systems. The use of paraffin wax as the PCM, was effective in absorbing and releasing heat, leading to improved thermal management of the PV panel and overall system performance.

The efficiency enhancement calculated through the experiment confirms that the PV-PCM system offers a promising solution for improving the efficiency and performance of solar panels, especially in areas with high solar irradiance.

The experiments conducted show efficiency improvements ranging from 3.8% to 6.5%, along with significant temperature reductions (up to 13.1°C) as in the table 2 below, which highlights the potential of PCM-based thermal management systems in enhancing the performance of photovoltaic solar panels.

Table 2 comparison between PV with PCM system and PV without PCM

Parameter	**Without PCM (Conventional)**	**With PCM (Thermal Storage)**
Panel Temperature	Higher, leading to efficiency loss	Lower, optimized for efficiency
Efficiency Improvement	Decreases with increased temperature	Increased by 3.5% to 6.5%
Peak Temperature Reduction	No control over excess heat	8.5°C to 13.1°C decrease
Average Efficiency Change	Decreases due to higher temperatures	Increases due to better thermal regulation

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REFERENCES:

[1] Green, M. A. (2015). Photovoltaic Solar Energy: Technology and Efficiency. Progress in Photovoltaics: Research and Applications, 23(10), 1335-1345.
[2] Farid, M. M., Khudhair, A. M., Razack, S. A. K., & Al-Hallaj, S. (2004). A Review on Phase Change Energy Storage: Materials and Applications. Energy, 29(6), 1189-1206.
[3] Yazdani, M., Sadeghzadeh, M., & Tabrizi, M. A. (2016). Effect of Phase Change Material on the Thermal Performance of Photovoltaic Systems: A Review. Renewable and Sustainable Energy Reviews, 58, 1347-1359.
[4] Candanedo, J. A., & Silva, J. M. (2011). Photovoltaic Panels Cooling Using Phase Change Materials: Experimental Study and Numerical Modeling. Solar Energy, 85(12), 3270-3283.
[5] Chou, S. K., Lee, K. H., & Yim, C. W. (2015). Experimental Performance of a Solar Cell with Phase Change Material (PCM) as Heat Storage Medium. Applied Energy, 144, 27-35.
[6] Dufour, J., Lau, K. K., & Saha, R. (2016). A Review of the Thermal Management of Photovoltaic Modules and Solar Energy Systems. Journal of Renewable and Sustainable Energy, 8(6), 1-19.
[7] Borges, C. A., Ribeiro, D. A., & Tavares, M. D. (2018). Enhancing Heat Transfer in PCM-Based Thermal Energy Storage Systems: A Review of Recent Advances. Applied Thermal Engineering, 132, 195-211.
[8] Li, H., Tian, H., & Zhu, H. (2017). Thermal Performance of Photovoltaic Systems with Metal Foams and PCM in Combination. Energy Conversion and Management, 142, 212-220.
[9] Soltani, P., & Sadeghzadeh, M. (2016). Performance Enhancement of Solar Photovoltaic Panels Using Thermal Energy Storage Systems with Phase Change Materials: A Review. Renewable and Sustainable Energy Reviews, 62, 291-300.
[10][1] Mahdi MN, Ibrahim MK, Mohammed HJ. Preparation and Characterization of Nano Membrane for Fuel Cell. DDF 2023;425:99–104. https://doi.org/10.4028/p-tsxt0p.