Design and analysis of energy-efficient solar panel cooling system using computational fluid dynamics
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Abstract
This paper highlights the design of an effective liquid cooling system that utilizes the heat generated from the solar panel as a cooling medium to maintain the optimal desired temperature of the solar panel. The coolant for this finned cooling system is selected based on its vaporizing temperature range and thermal cycle characteristics. For analysis purposes, a CAD model is generated in Solidworks CAD package, and further meshing and numerical simulations are performed using Ansys Fluent software. Flow and heat transfer characteristics of the cooling system are investigated by plotting stream functions, velocity, and temperature distributions inside the system. Probing of variations in temperature, pressure and turbulent kinetic energy along vertical as well as longitudinal direction is graphically analysed. Thus, elucidating characteristic of parametric conditions under observation. This study's results can be the potential background for designing an efficient solar panel cooling system with superior thermal performance.

1. Introduction
Even though, in the presence of surplus sunlight, high-temperature regions fail to exploit their maximum potential due to high thermal generations in the solar panel. The temperature has an adverse effect on panel output. Advanced cooling technology uses external thermal absorbent to reduce panel temperature. This research paper has proposed a model to use low vaporization point liquid chemical as a heat absorbent to reduce solar panel surface temperature. Without any external source energy and by using material properties to our advantage, we accomplished the same. The paper includes a simulation study conducted using Ansys Fluent software. Peng et al. [1] carried out an experiment in two different phases. In the first phase, they analyzed the relation between the effect of solar radiation, power output, and efficiency of the solar panel. In the second phase, they conducted a cooling experiment and concluded that it increases solar output efficiency. Agarwal [2] main idea behind the study is to review the literature on photovoltaic cooling techniques with the help of phase change materials (PCM), including PV-thermal systems and building integrated photovoltaic systems. The objective is to identify important research areas to verify the reliable performance and commercial viability of the technology. Various parameters need to be evaluated and optimized for the geographical location of interest for getting the best output, a hike in electrical efficiency as high as 5% is observed with PV-PCM integrated systems. Moharram et al. [3] objective of his research was to minimize the amount of water and electrical energy required for cooling solar panels, especially in hot arid regions, e.g., desert areas of Egypt. A cooling system was developed based on a water spraying mechanism for PV panels. With the help of the mathematical model, the cooling of the solar panel is determined. A cooling model is proposed to determine how long it takes to cool down the PV panels to their normal operating temperature. Bhaskar et al. [4] Objective of the present work is to design a Water-cooling system for the solar cell to optimize electrical efficiency and to extract heat energy. A hybrid system that simultaneously generates both electrical energy and heat energy is considered. This
A hybrid system contains photovoltaic cells attached to an absorber plate with fins attached to its reverse side. A simulation model is prepared, and performance curves are obtained for a single pass, single duct solar collector with fins. Waqas [5] discussed the electrical and thermal management of PV systems integrated with Phase Changing Materials. The purpose of this article is to provide current know-how of PV-PCM technology, simultaneously stating research gaps and challenges faced. They provided a detailed elaboration of different aspects such as PCM selection, system development, performance evaluation, simulation, and heat transfer enhancement, along with cost estimation. Rajvikram M. et al. [6] proposed solution focuses on the efficiency of PV panels with Phase Changing Materials and aluminum sheet as TCE. This experiment was performed under direct sun rays for three months. They performed an experiment using two 5 W panels, and results were compared with naturally ventilated panels without PCM and aluminum. Li et al. [7] Research demonstrate a high operating temperature of crystalline silicon-based photovoltaic (PV) module would eventually lead to a decrease in efficiency and lifetime. They attached PCM at the back of the PV module in PV-PCM system format in order to absorb excess heat. Kang et al. [8] heat transfer performance of silicon oil immersion cooling densely packed solar cells were studied and analyzed, with and without fin structure, using experiment and simulation methods. The results showed that solar cells temperature declined and distributed fairly as silicon oil inlet flow rate increases; however, the temperature of the solar cells improved linearly. Mehrotra et al. [9] In this research paper author says that If we submerged PV cells in water, that is beneficial to maintain its surface temperature. It's also provided better efficiency at very high or extreme temperatures. The author calculated the electrical parameter and the cooling factor. This calculation elaborates upon the cooling factor that also favors electrical efficiency enhancement. Here temperature variation is from 304-312K. Abdulgafar et al. [10] Photovoltaic cell cooling is studied in distilled water immersion conditions of a polycrystalline panel at different depths. With the increase in depth, an evident increase in efficiency was observed. Thakur et al. [11] In this research paper author proposed the utilization of heat generated by the panel with a heat pump, and it can be used in various fields. He supported his conclusion through mathematical relationships. Haller et al. [12] In this paper, the author proposed two methods to increase the efficiency of a solar panel system. First, by liquid immersion, and secondly, he proposed a design that utilizes an air blower to curb temperature surge. Singh and Kumar [13] a shell and heat exchanger tube are considered where; hot water is flowing through a tube, and cold water runs outside but still in the shell. CFD technique resolves the heat exchanger in individual elements to find the temperature gradients, pressure distribution, and velocity vectors. Egon et al.[14] this research paper answers all requires related to CFD analysis along with information about boundary conditions, numerical grid, and initial condition information. Chen et al. [15] give a detailed 3-D computational fluid dynamics analysis of gas particles that are falling on the solar receiver panel using the Euler-langrange method and also give momentum analysis of these particles. Cho et al.[16]used CFD and DEM (discrete element method) to analyze the flow of gas-solid particle collision model. There are also numerous experimental [16-20] and analytical models [21-25] developed to estimate the flow and heat transfer characteristics in enclosures. Sumedha et al.[26]mentioned that because of using the non-renewable resources people have noticed the bad impact of it on Earth pollution, Climate Change so people are forced to use renewable resources like solar panel. He has mentioned drawback of the solar cells like it will not work in the night time, cleaning problems etc and mentioned innovative ways and technologies to solve this problem. Arifin et al.[27] mentioned the bad impact of using conventional resources. When solar cell is placed where sun intensity is too high its efficiency decrease with the increase in temperature. Author has proposed passive cooling system where we use heat sink and fins to increase the efficiency of the solar panel. Author has carried out experiment with different number
of fins with heat sink and finds out that if anybody use 15 number of fins with heat sinks it will where temperature is 10 degree Celsius efficiency will increase by 2.74%.

Our concept idea aim is to iterate and perform CFD analysis for a system that can be a potential candidate for an efficient cooling system by using material’s characteristic properties to our advantage. While comparing other materials, carbon disulphide’s boiling point is not too high that may turn it into vapour immediately nor too low that may resist it’s vapour generation at experimentation conditions. From the experimental data we have collected carbon disulphide show optimum chemical properties for this experiment. Even though it being a bit reactive material when exposed to hot surfaces, it’s reactivity can be undermined by mixing it with water and that may increase the boiling point/ vapourizing point of the liquid.

| Molar mass          | 76.13 g·mol⁻¹ |
|---------------------|---------------|
| Appearance:         | Colourless liquid |
| Impure Appearance:  | light-yellow  |
| Melting point       | -111.61 °C    |
| Boiling point       | 46.24 °C (115.23 °F; 319.39 K) |
| Refractive index (nD) | 1.627        |
| 82.4 kPa (40 °C)    | 82.4 kPa (40 °C) |

Table 1: Properties of carbon disulphide:

Thus, performing a virtual simulation and obtaining expected results for the same. Though, no physical experimentation was performed using carbon disulphide, a guideline to follow for handling and using carbon disulphide is as follows.

Handling – Keep it away from any flammable source, wear a body suit before operating hence avoid breathing vapours. Use personal equipment like gloves and shoves to cover whole body.

Solar panels are made of material that are highly corrosion resistant. Modules of the solar panels are sealed with the help of the vacuum between their sheet and materials. This sealing will prevent any corrosion due to carbon disulphide until and unless there is crack in your panel. Our system is a solar panel enclosed and immersed it in carbon disulfide liquid with the top of enclosing being transparent for sunlight to enter. The transparent surface has augmented surface area by incorporating a step patterned surface, facilitating heat transfer rate enhancement. Due to low vaporization temperature, the liquid absorbs heat and starts evaporating in the range of 45-50-degree Celsius. In the upper section of the casing, due to increased surface area, the heat transfer rate accelerates, and vapors start condensing. This liquid confluence and adds up to the liquid source at the bottom of the case, adhering to the slope of the enclosure. For this process, we analyze heat flow, vapor velocity, pressure, and heat transfer with the assist of ANSYS fluent software.
2. Methodology

![Cross-section of the enclosure](image)

The solar panel is enclosed and fixated to the bottom of an aluminum casing (thermal conductivity 205 W/mK) of net volume 0.03m$^3$ of base length and width being 0.577m and 0.354m respectively. Covered by transparent glass (thermal conductivity 0.8 W/mK) for inflow of sunlight, with enhanced surface area; dimensioned - 0.366m, 0.019m and 0.024m for length, breadth and height respectively of the fins. immersed in carbon-disulfide, which has a boiling point of 46 degrees Celsius. Thermal energy is harnessed by the liquid, and when the temperature approaches boiling point, the liquid starts vaporizing. These vapors move upwards, clings, and amalgamate on the wall of the case. These droplets slide over the slant surface and flow back into the sink. This cycle repeats until the temperature falls below 35 degrees Celsius. The system utilizes heat energy generated by solar panels to cool panels and thereby increasing efficiency.

The system is designed to automatically regulate solar panel surface temperature by using low vaporization temperature liquid and augmented surface area. The lower section of the system is filled with Carbon disulfide with a panel immersed in it.

### 2.1.1 Calculation

As shown in the figure in the cl are material will go through conduction:

\[
R = \left(\frac{1}{k\alpha}\right)
\]

R=resistance
K=thermal conductivity of material  
A=surface area

![External surface](image)

![Internal surface](image)

Figure 2: dimensional diagram of an outer surface of the case

In the C2 region, material will go through convection: (Air and glass surface convection)

**Case 1:**
Laminar-turbulent constant wall temperature

$$\text{Nu}_x = 0.037 \cdot (\text{Re}_x^{0.8} - 871) \cdot \text{Pr}^{1/3}$$

(2)

Re=Reynold number  
Nu=Nusselt number  
Critical Reynold number =5*10^5 < Pr < 60

**Case 2:**
High-speed flow, constant wall temperature:

Q=\(hA\left[\text{T}_w-\text{T}_a\right]\)

And our final C3 region will go under conduction: (vapour glass surface contact)

$$R = \left(\frac{1}{h'\alpha}\right)$$

(3)

Using C1, C2, C3, we will find
Total heat transfer/Area by C1, C2, C3

Amount of heat required to be transferred to maintain the temperature at 40 degree Celsius at an ambient temperature of 30 degree Celsius (at steady state). In the final step, we will equate both to get the amount of surface area required at a steady state.
Grashof Number - \( G = \frac{\beta g (T_w - T_{\infty}) L^3}{\nu^3} \)
\( G = (1.15 \times 9.81 \times |35 - 50| \times ((108.01958)^3)) / (0.298^2) \)
\( G = 2401778.936 \)
\( = 2.40 \times 10^6 \)

| Abbreviations | Nomenclature |
|---------------|--------------|
| R             | Resistance (K·m²/W ) |
| K             | Thermal conductivity of material(W/m·K) |
| A             | Surface area(m²) |
| Re            | Reynold number |
| Nu            | Nusselt number |
| Pr            | Prandtl number |
| Tw            | Wall temperature(°C) |
| h             | Heat transfer coefficient (W/m²k) |
| Tat           | Temperature of surrounding |
| C1            | Region for heat flow |
| C2            | Region for heat flow |
| C3            | Region for heat flow |
| Re            | Reynolds number |
| Q             | Heat transfer rate(W) |
| G             | Grashof Number |
| g             | Gravitational acceleration (m/s²) |
| \( \beta \)   | Coefficient of volumetric expansion |
| Ts            | Temperature at the surface (°C) |
| T\(_{\infty}\) | Temperature far from surface (°C) |
| L             | Characteristic length (m) |
| v             | Kinematic viscosity of fluid (m²/s) |
3. Results and Discussions:

Figure 3 indicates the schematic diagram of the solar panel cooling system and meshed geometry is shown in Fig. 4. Figure 5 shows the velocity distribution of carbon disulphide inside the solar panel enclosure and multi recirculating convective cells are seen evolving inside the solar panel cooling system. Figure 6 and 7 indicates the turbulent kinetic energy and energy dissipation rate inside the solar panel system. Since excited vapours tend to move upwards due to high kinetic potential and exert force on each other by random collision, high turbulent kinetic energy is observed in the gas filled section of the chamber compared to lower liquid filled section. Moreover, due to smaller volume availability to vibrate and collide freely near the fins due to walled boundaries, more turbulence is
observed in the middle section of gas volume then in upper section adjoin to fin’s upper section. Similarly, due to the very same reason higher dissipation is observed on the lower fin section then upper fin section. Figure 8 shows the temperature distribution due to convective heat transfer and carbon disulphide near the hot panel surface absorbs heat and diffuses the heat inside the solar panel system.

Figure 5: Y directional velocity flow of carbon disulfide

Figure 6: Turbulent kinematic energy flow in the enclosure
Figure 7: Turbulent Dissipation rate in the enclosure

Figure 8: Temperature variation of the enclosure

Figure 9 and 10 indicates the temperature and pressure variation inside the solar panel along the longitudinal direction for different inclination angles of solar panel. It is seen that the temperature distribution inside the enclosure decreases with increase in the inclination angles of solar panel.
However, an opposite trend is observed in the pressure distribution inside the enclosure. Figure 11 and 12 represents the pressure and turbulent kinetic energy variation for different solar panel elevations. Table shown in Figure 13 is tabulated by probing variations in temperature, pressure and kinetic turbulent energy along vertical as well as longitudinal axis at specific intervals.

![Figure 9: Temperature variation along the longitudinal direction](image9)

![Figure 10: Pressure variation along the longitudinal direction](image10)
Figure 11: Pressure variation inside solar panel

Figure 12: Turbulence kinetic energy variation inside solar panel
Table 2: Tabulation of Temperature, Pressure and T.K.E. with respect to X-Y plane

| X (m) | Y (x0.1m) | Temperature (K) | Pressure (P)       | Turbulent K E (J/Kg) |
|-------|-----------|----------------|--------------------|----------------------|
| 0.1   | 1         | 331.27         | -7.46E-16          | 0.007691876          |
| 0.1   | 3         | 332.38         | -1.06E-15          | 0.005234927          |
| 0.1   | 4         | 332.41         | -2.91E-15          | 0.006809396          |
| 0.1   | 6         | 331.67         | -3.26E-15          | 0.012323185          |
| 0.1   | 8         | 321.96         | -3.60E-15          | 0.000978513          |
| 0.2   | 1         | 332.06         | -3.23E-16          | 0.000320973          |
| 0.2   | 3         | 332.99         | -1.82E-15          | 0.002436296          |
| 0.2   | 4         | 332.49         | -2.91E-15          | 0.007264425          |
| 0.2   | 6         | 331.80         | -3.26E-15          | 0.013181454          |
| 0.2   | 8         | 315.32         | -3.60E-15          | 0.000266505          |
| 0.3   | 1         | 332.12         | -2.03E-16          | 0.000317751          |
| 0.3   | 3         | 332.99         | 1.46E-15           | 0.002485905          |
| 0.3   | 4         | 332.49         | -2.91E-15          | 0.007275655          |
| 0.3   | 6         | 331.81         | -3.25E-15          | 0.013414463          |
| 0.3   | 8         | 316.29         | -3.60E-15          | 0.000355239          |
| 0.4   | 1         | 332.06         | -1.55E-17          | 0.000358472          |
| 0.4   | 3         | 332.99         | -3.63E-16          | 0.002419203          |
| 0.4   | 4         | 332.49         | -2.91E-15          | 0.007262155          |
| 0.4   | 6         | 331.81         | -3.25E-15          | 0.013435755          |
| 0.4   | 8         | 321.86         | -3.60E-15          | 0.001005924          |
| 0.5   | 1         | 331.17         | 1.07E-16           | 0.00603221           |
| 0.5   | 3         | 332.49         | -4.37E-16          | 0.004244912          |
| 0.5   | 4         | 332.47         | -2.91E-15          | 0.006890195          |
| 0.5   | 6         | 331.73         | -3.26E-15          | 0.012328816          |
| 0.5   | 8         | 313.04         | -3.60E-15          | 0.000121543          |

4. Conclusion:

Using carbon-disulfide as a phase changing heat absorption material, panel heat could be absorbed, and the efficiency of the system could be increased. The numerical simulation is performed using finite volume method to analyse the heat and flow characteristics inside the solar panel with carbon-disulfide as phase change material. Based on the graphical interpretation of data, we can conclude that pressure, kinetic turbulence energy, and the ambient temperature inside the enclosure increase with the increase in panel temperature and is maximum above the panel and minimum along the sides of the casing. In the vertical direction, the temperature and pressure are maximum at the liquid-gas interface and minimum on the condensing boundary. Contrasting to it, the turbulent kinetic energy is maximum in the air-vapor phase region. The results from the present study will be useful in designing an effective solar panel cooling system.
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