To What Extent Do Liquid Coolants Impact the Efficiency of Solar Panels?

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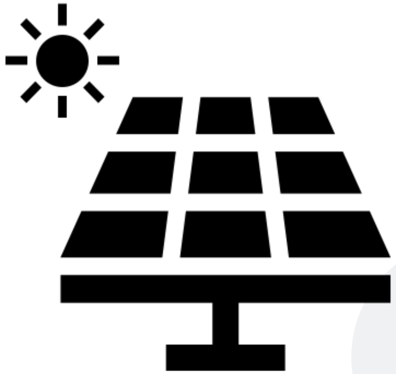
Introduction

As Solar Energy becomes an increasingly crucial source of renewable energy, increasing economy of solar panels is an engineering challenge.

- Increasing its efficiency in converting solar irradiance to usable electricity is critical.



Overheating is one of the key factors that affect efficiency of a solar panel

- The semiconductors used in solar panels are sensitive to high temperature
- Their efficiency reduces by 0.5% for every degree Celsius rise above the optimum temperature of 25 degrees Celsius

Wider Implications of Reduced Efficiency

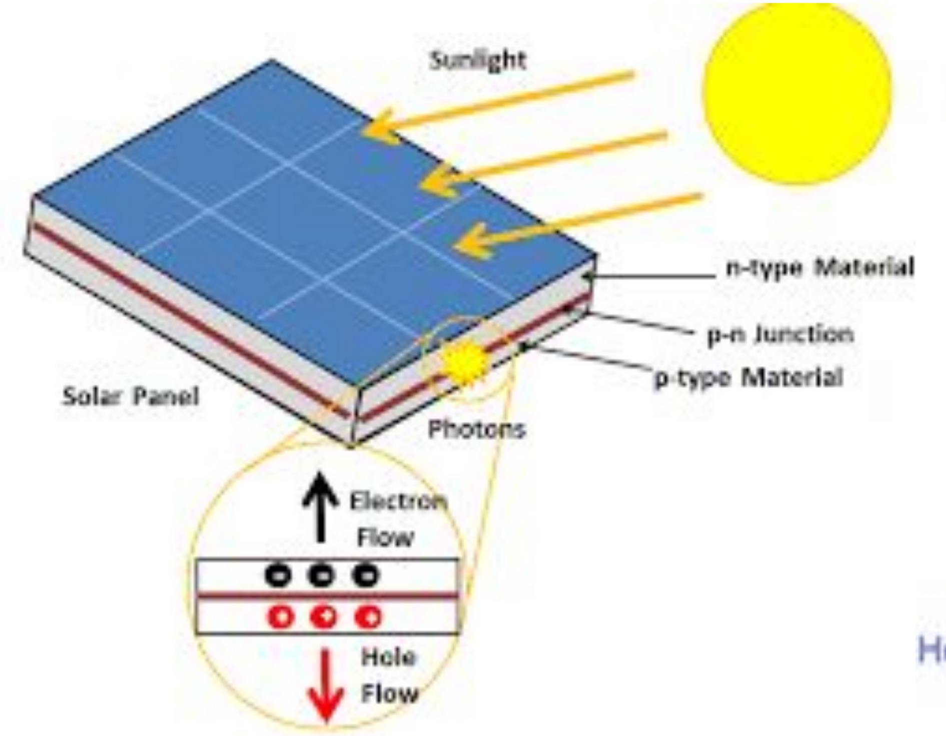
INEQUITABLE ACCESS TO ENERGY, ESPECIALLY CLEAN ENERGY, ESPECIALLY FOR DEVELOPING AND UNDER-DEVELOPED COUNTRIES.

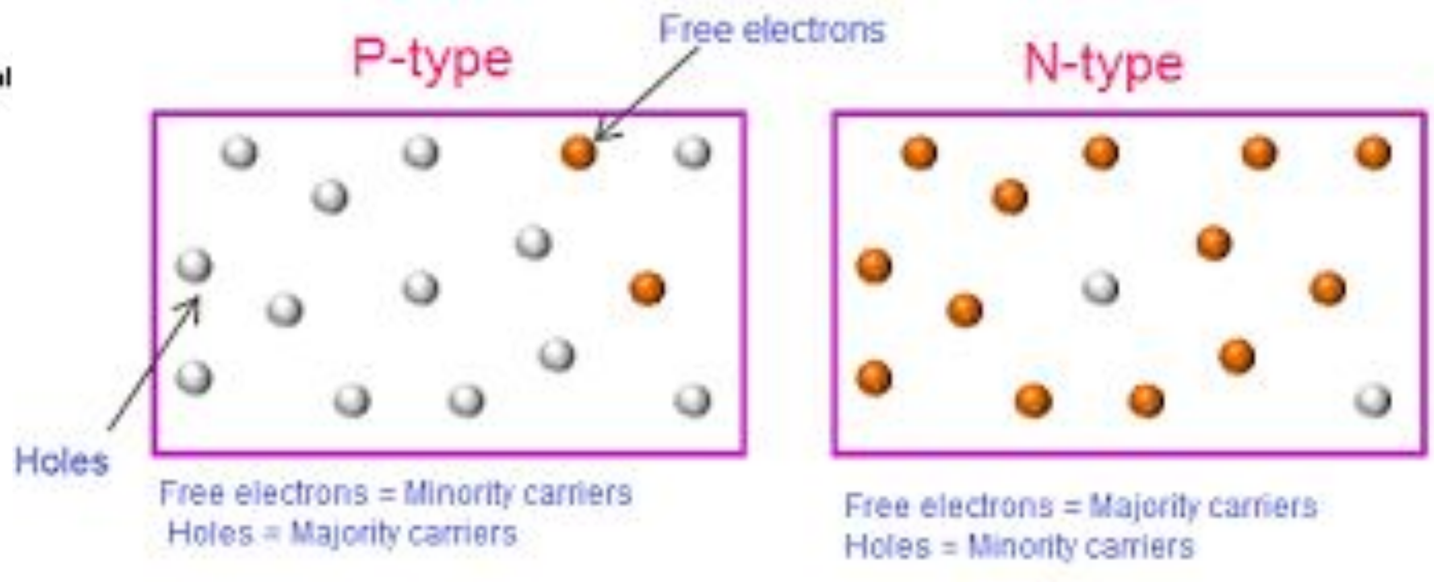
INCREASED OPERATING COST OF DEVICES THAT USE SOLAR PANELS.

WITH WATER AS A WIDELY USED COOLANT, ALTERNATE COOLANTS NEED TO BE EXPLORED, GIVEN CRISIS OF FRESH WATER.

The research, by elaborating the impact of various coolants with unique specific heat capacity on the efficiency of solar panels, aims to throw light on the relation, if any, between specific heat capacity and solar panel efficiency.

It explores the possibility of using alternative coolants in ameliorating the adverse effect of overheating of the solar panels.





Secondary Research: Science of Solar Panels & Role of Coolants

$$R_{SRH} = \frac{n \cdot p - \left(n_i(T_o) \cdot e^{\left(\frac{E_g(T_0) - E_g(T)}{2kT} \right)} \right)^2}{\tau_n \cdot (p + p_1) + \tau_p \cdot (n + n_1)}$$

1. An expression for the rate of SRH recombination including the expression for intrinsic carrier concentration

$$E_g(T) = E_g(T_0) - 2kT\left(\ln\left(\frac{n_i(T)}{n_i(T_0)}\right)\right)$$

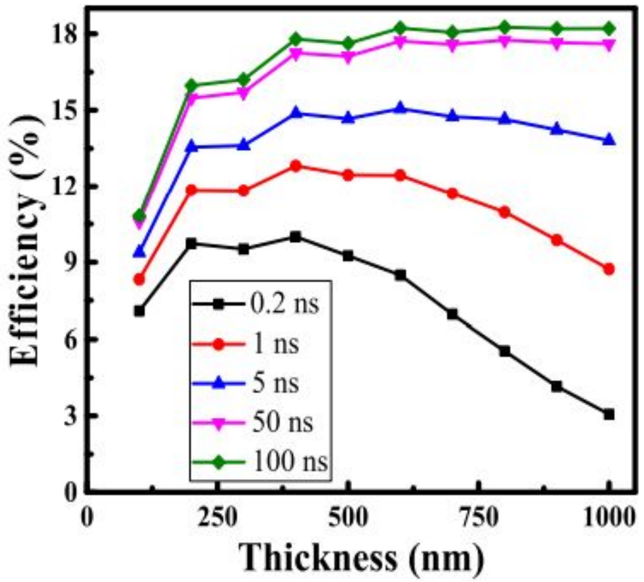
2. An expression for the relationship between the size of the band gap and temperature.

$$V_{oc} = \frac{E_g(T_0) - 2kT\left(\ln\left(\frac{n_i(T)}{n_i(T_0)}\right)\right)}{e} - \frac{kT}{e}\ln\left(\frac{N_{eff}^2}{n \cdot p}\right)$$

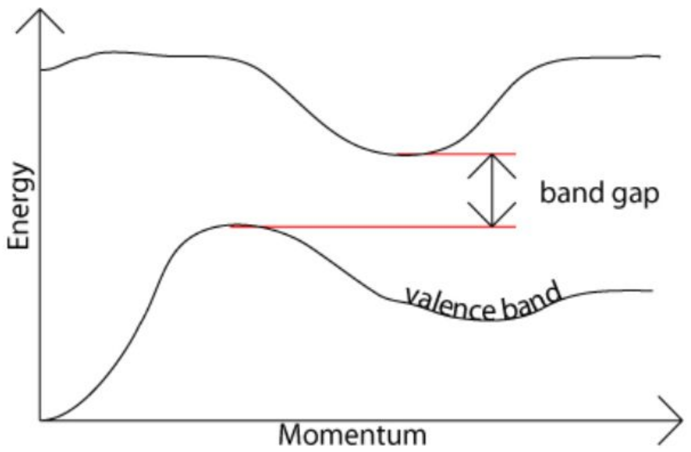
3. An expression for the correlation between the Open Circuit Voltage (V_{oc}) and intrinsic carrier concentration (Diebel).

$$Max\ Efficiency = \frac{\left(\frac{E_g(T_0) - 2kT\left(\ln\left(\frac{n_i(T)}{n_i(T_0)}\right)\right)}{e} - \frac{kT}{e}\ln\left(\frac{N_{eff}^2}{n \cdot p}\right)\right)^2}{R \cdot (Solar\ Irradiance \cdot Area\ of\ Solar\ Panel)} \cdot 100$$

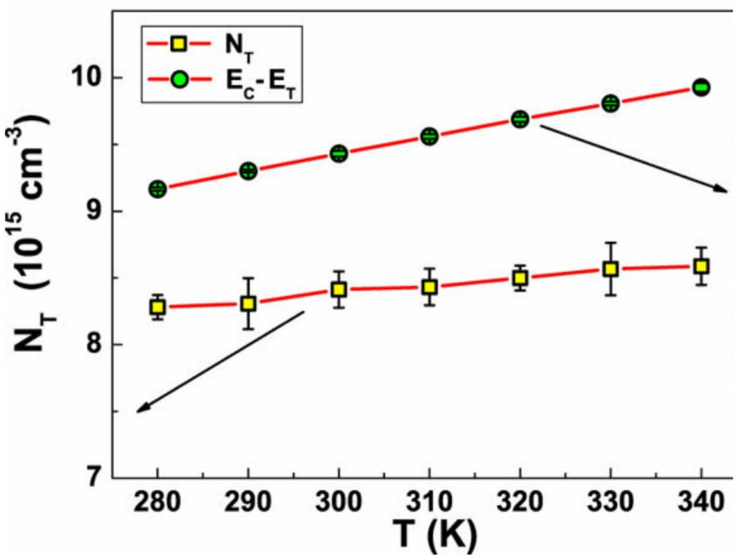
4. The final expression for the maximum efficiency achieved by a solar panel.



Relationship between the efficiency of a solar panel and carrier lifetime. (Shukla et al.)



The k-space for an indirect band gap semiconductor. (University of Cambridge)



Defect Density Concentration v. Temperature (Landi et al.)

Hypothesis

Solutions with higher specific heat capacities are more effective as coolants, as they absorb more heat without seeing a large rise in their own temperatures

Thus, coolants with higher specific heat capacities are expected to be more effective in cooling down solar panels.

By reducing the surface temperature of solar panels, coolants should also bring about an improvement in the efficiency of solar panels.

Experiment: Change in efficiency of a solar panel when treated with the following liquid coolants with different specific heat capacity:

Coolant Used	Specific Heat Capacity ($kJ\ kg^{-1}\ K^{-1}$)
Cooking Oil (Solar Panel 5)	1.9
Ethylene Glycol (Solar Panel 1)	2.42
Ethanol (Solar Panel 4)	2.46
Soapy Water (Solar Panel 3)	3.15
Distilled Water (Solar Panel 2)	4.18

Variables

- Independent Variable: Specific Heat Capacity of Coolant (2 kJ kg^{-1} K^{-1} to 4.5 kJ kg^{-1} K^{-1})
- Dependent Variable: Efficiency of solar panel (%)
- Control Variables
  - Angle of the solar panel
  - Time of the day when the data is collected
  - Volume of coolants
  - Material and surface area of solar panels
- Extraneous Variables:
  - Amount of dust collected on solar panels
  - Albedo of coolants
  - Fluid viscosity

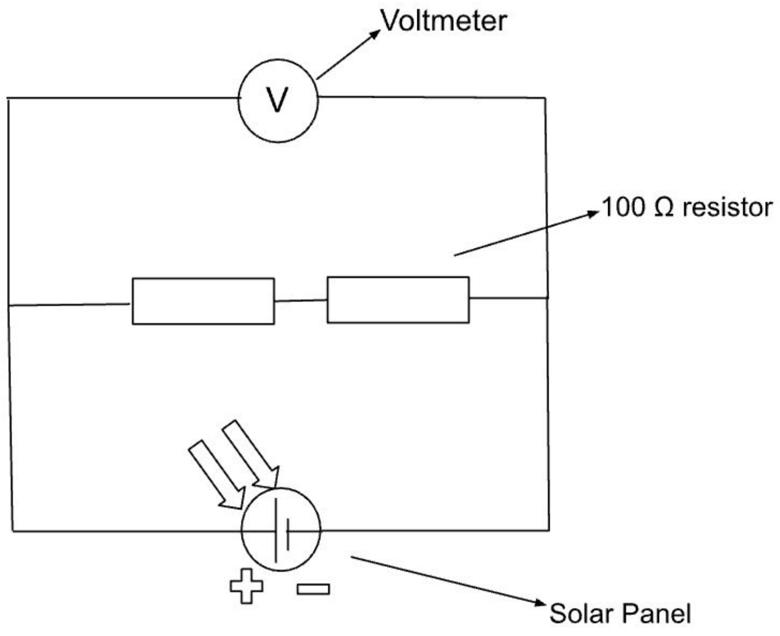
Methodology and Procedure

The coolant was made to flow on the top surface of the solar panel through holes in the bucket holding the coolant. Identical buckets were used with identical size and placement of holes. The coolant was collected back in a bucket placed below the panel.

For each trial (total 5 trials), Solar Irradiance and Voltage was measured. Next each solar panel was treated with the fixed volume of one of the 4 coolants. The voltage after each treatment was calculated.

Using specific formula, Change in Voltage, Power $_{in,}$ Power $_{out}$ and Change in Efficiency was calculated.

The experiment was conducted during the months of May 2024 and June 2024 outside the laboratory of Cairo American College, Egypt.



Results: Initial and Final Efficiency for each trial

Coolant	Initial Efficiency Trial 1 (%) ± 0.006	Final Efficiency Trial 1 (%) ± 0.006	Initial Efficiency Trial 2 (%) ± 0.006	Final Efficiency Trial 2 (%) ± 0.006	Initial Efficiency Trial 3 (%) ± 0.006	Final Efficiency Trial 3 (%) ± 0.006	Initial Efficiency Trial 4 (%) ± 0.006	Final Efficiency Trial 4 (%) ± 0.006	Initial Efficiency Trial 5 (%) ± 0.008	Final Efficiency Trial 5 (%) ± 0.008
Ethylene Glycol	6.80	7.57	6.53	7.57	6.45	7.52	5.85	6.87	8.42	9.70
Distilled Water	7.03	8.08	6.68	8.17	6.60	7.93	6.01	7.06	8.42	9.70
Soapy Water	7.16	8.10	6.94	8.02	6.86	7.84	5.96	7.20	8.66	10.06
Ethanol	6.81	8.05	6.68	7.81	6.34	7.58	5.90	6.82	8.58	9.86
Cooking Oil	7.10	7.48	6.59	6.89	6.80	7.35	5.72	6.45	8.50	9.70

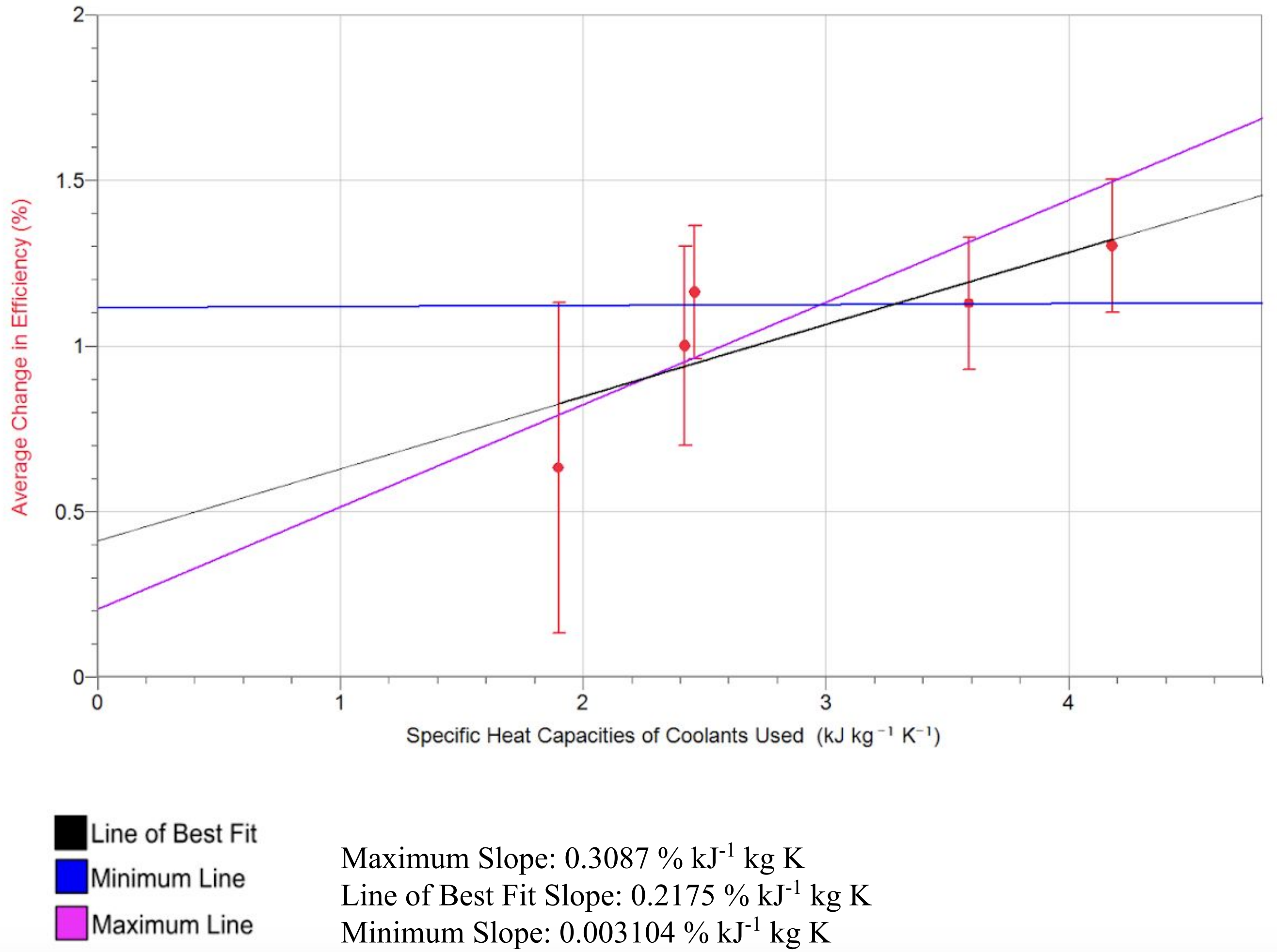
Results: Change in Efficiency for each trial

Coolant	ΔEfficiency Trial 1 (%) ± 0.01	ΔEfficiency Trial 2 (%) ± 0.01	ΔEfficiency Trial 3 (%) ± 0.01	ΔEfficiency Trial 4 (%) ± 0.01	ΔEfficiency Trial 5 (%) ± 0.02	Average ΔEfficiency (%)	Uncertainty in Average ΔEfficiency (%)
Ethylene Glycol	0.77	1.04	1.07	1.02	1.28	1.0	± 0.3
Distilled Water	1.05	1.49	1.33	1.36	1.28	1.3	± 0.2
Soapy Water	0.94	1.08	0.98	1.24	1.40	1.1	± 0.2
Ethanol	1.24	1.13	1.24	0.92	1.28	1.2	± 0.2
Cooking Oil	0.38	0.30	0.55	0.73	1.20	0.6	± 0.5

Average Change in Surface Temperature Brought About by Coolants

Coolant	Average Change in Surface Temperature (°C) ± 0.1
Ethylene Glycol	22.45
Distilled Water	25.53
Soapy Water	27.03
Ethanol	26.73
Cooking Oil	23.40

Average Change in Efficiency VS. Specific Heat Capacities of Coolants Used



Maximum Slope: 0.3087 % kJ^{-1} kg K
Line of Best Fit Slope: 0.2175 % kJ^{-1} kg K
Minimum Slope: 0.003104 % kJ^{-1} kg K

Conclusion

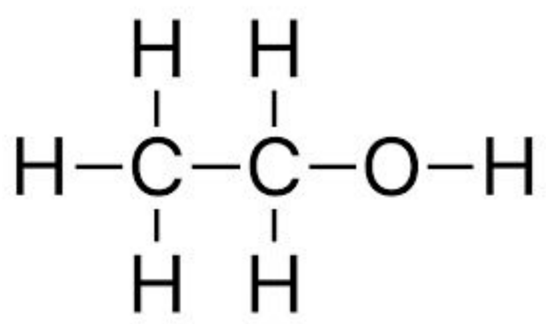


Image Source

- The experiment shows that solar panels showed an increase in efficiency after treatment with a coolant. Further, it confirms the hypothesis that a coolant with a higher specific heat capacity is more effective in increasing the efficiency of the solar panel.

- Ethanol stands as an outlier – despite a lower specific heat capacity than soapy water, it showed a higher change in efficiency of the solar panel, post treatment. This could be attributed to better thermal conductivity and low viscosity of ethanol as compared with soapy water where the presence of soap could have affected its evaporation and rate of cooling.

- It is advisable to use coolants that produce minimal fluctuations in the output of solar panels so as to no have large impact on the longevity of the panel by enabling it to deliver optimum output consistently within the optimum temperature range. All the coolants used in the experiment produced minimal fluctuation in the output of the solar panels, as illustrated by the relatively small size of the error bars.

Questions?

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