Efficiency of PV/T cooling system

Abstract

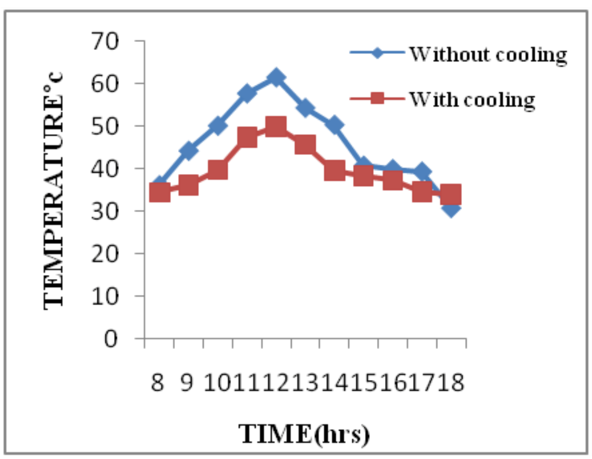
Photovoltaic (PV) cells have a number of factors such as operating temperature that affect the efficiency of the cells. A photovoltaic cell is a device that converts sunlight into electricity. This study is designed to determine the best fluid and parameters to cool a PV cell to the optimum operating temperature for the best efficiency of the cell. The study will use MATLAB Simulink to simulate a simple test system of a heat generation component and a heat absorption component to test a variety of fluids, pressures, and flow rates.

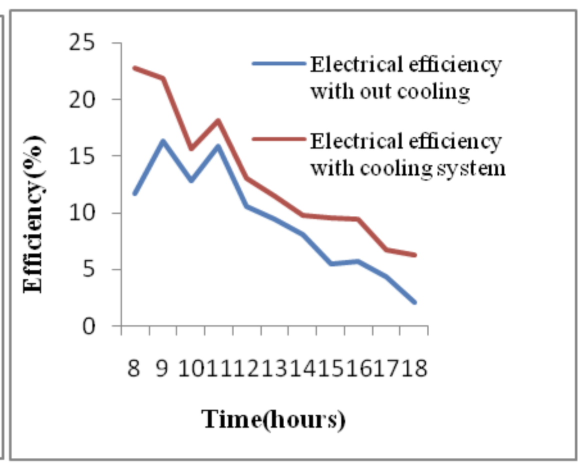
Introduction

Renewable sources of energy have been increasing in presence since the early 2000. The rapid increase in population makes a drastic increase in energy demand, and we are coming to the point that fossil fuels are not being enough and also are damaging the environment and changing the way we live.

Within renewable sources of energy, solar energy has been growing for the past ten years. It uses the radiation from the sun and transforms it into power through a p-n semiconductor junction. A p-n junction is a junction that exists between a positively charged semiconductor and a negatively charged semiconductor [12]. The p-n junction produces electricity from the sun using the photovoltaic effect [16]. The photovoltaic effect is where the photons produced by the sun connect with an electron and cause a current to form as the electron is then free to move [1]. Its advantages vary from its high reliability, low maintenance cost, and also it doesn’t produce noise pollution. One of the only throwbacks of this kind of energy is that it is temperature sensible. This means that as the temperature of the photovoltaic module increases, the power output from the cells will decrease. The voltage is highly dependent on temperature, so it explains the voltage drop as temperature increases.

The type of PV used is the primary influencer in the electrical performance. The average PV module transforms around 6-20% of the incident solar radiation that receives [4]. The rest of the incident solar radiation transforms into heat, which decreases the efficiency [18]. Most PV cells are created and tested to be the most efficient at 25 degrees Celsius or about 77 degrees Fahrenheit [5]. In a study in 2012, researchers found that when a PV cell is actively cooled, the efficiency of the cell can increase from 8 to 9 percent up to 14 percent [13][19].





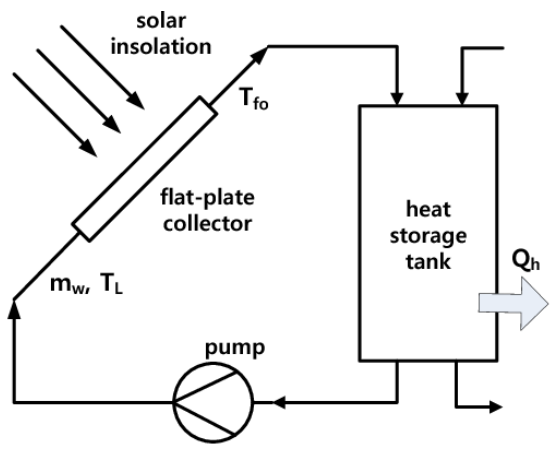
In order to solve this problem and increase the PV’s efficiency some researchers have been working on ways to collect that extra heat to cool the PV.

- PV/T liquid collector uses a liquid based design that uses a channel to direct fluid flow using piping of various materials or plates attached to the back of a PV module. It typically uses water, glycol, or mineral oil to redirect the heat absorbed from the PV modules. In closed-loop systems this heat is either exhausted (to cool it), or transferred at a heat exchanger, where it flows to its application. In open-loop systems, this heat is used, or exhausted before the fluid returns to the PV cells [11].
- PV/T spray cooling device cools the PV modules by using ten nozzles in each side of the PV modules that spray water to dissipate the heat accumulated by the material of the PV cells [14][10].
- PV/T air collector uses a conductive hollow metal housing to mount the PV modules. Heat is radiated from the panels into the enclosed space, where the air is either circulated into a building HVAC system to recapture heat energy or rises and is vented from the top of the structure. Without active cooling, the temperature of the module was high and solar cells can only achieve an efficiency of 8–9%. However, when the module was operated under active cooling condition, the temperature dropped significantly leading to an increase in efficiency of solar cells to between 12% and 14% [11][6].
- PV/T Heat sink uses high thermal conducting metals to remove heat from the PV cells. The power increase by this method was accounted for a 6.97%-7.55% compared to not using it [14].
- PV/T fins cooling uses aluminum fins combined with cotton wick as a passive cooling system to maintain the temperature of the PV modules. It managed to reduce the maximum temperature by 12% and increased the output power by 14% [14][2].

In this project, computer simulations will be performed using MATLAB Simulink to experiment with a number of factors to increase the efficiency of the PV cell by removing the excess heat from the PV Cell and moving it to a location that it then can be used to generate more power [7][8][3]. The basic model will be a heat sink that is adding heat to a fluid like a PV cell would and a heat collector to act as the component that is using the heat. Between the two main components will be a closed loop with a fluid and possibly a pump to circulate the fluid. The main focus of the project is the fluid that is being used to transfer the heat from the PV cell to the power generator. In previous studies, water and air have been used to cool the PV cells, so in this experiment, less common fluids will also be used in comparison to water to find the most effective cooling/heat transfer fluid [9]. In the simulations, the fluid type, pressure, and velocity will be changed to find the point where the greatest efficiency is created for the PV cell.

Method:

For our project we are going to use a heat sink. There are several types of heat sinks that are already in use for Photovoltaic cells heat absorption. PV/T liquid collector uses a liquid based design that uses a channel to direct fluid flow using piping of various materials or plates attached to the back of a PV module. It typically uses water or coolant fluid to redirect the heat absorbed from the PV modules. In closed-loop systems this heat is transferred to a heat exchanger, where it flows to its application. We are going to use the total amount of energy moved to lower the temperature of the PV related to PV cell efficiency curve.



The heat transferred and the thermal capacities are important parameters for our thermal analysis. The heat is transferred to the PV by solar insolation and then with convection we can adjust the temperature of the PV cells. Now we calculate the total amount of energy input where Q is the solar irradiation [15].

$$E_{in} = Q \times A$$

For the output thermal energy extracted by the cooling liquid is calculated by the following equation. In this equation: ṁ is the mass flow rate of the water, C_p is the specific heat capacity of the liquid, T_{Out} is the temperature of the liquid after absorbing all the heat from the PV, T_{in} is the temperature of the cold liquid [15].

$$E_{liquid} = \dot{m} * C_p(T_{Out} - T_{in})$$

Once we have the energy of the water, we can calculate the thermal efficiency with the following equation [15].

$$\eta_{Thermal} = E_{water} \,/\, E_{in}$$

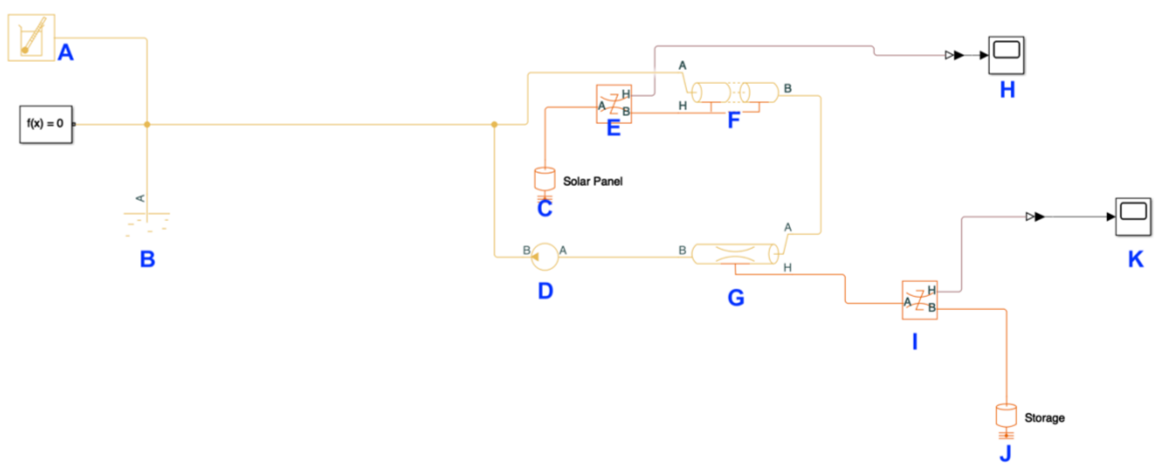
Finally, depending on the values that we get from the efficiencies and the model, we will be playing around with different types of liquids. Also, we will be trying out within each liquid different pressures and mass flow rates to accomplish our final goal that is to cool the PV as much as possible and accumulate the heat extracted in the tank where later could be used for another purpose.

Material:

For our experiment we are going to use copper tubing with water flowing through it. We are choosing copper because it is a very good heat conductor (385 W/m K) and water absorbs heat better that air and also it is very easy to find and use with no risk of contamination or intoxication that could happen with coolant fluids.

Results & Discussion

To determine what fluid, pressure and mass flow rate was the best to move the heat from the solar panel to the energy storage device MATLAB simscape was used to model a basic system. The basic system included a heat input, a place to store the heat, and a fluid to move the heat energy from one location to the other. To determine the best fluid and parameters to use the temperature graphs of the solar panel will be analyzed to determine what cools the solar panel the fastest and remains at the most constant cool temperature.

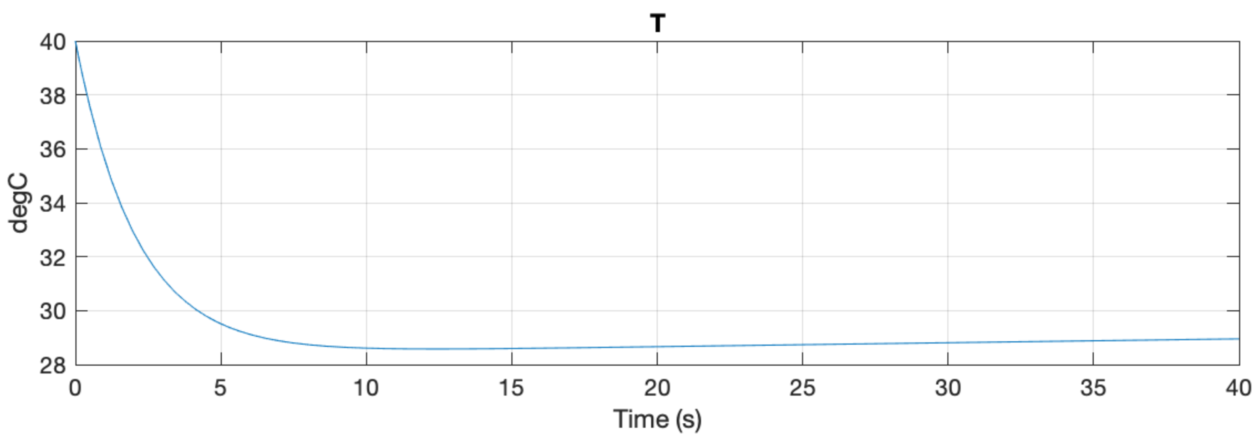


This figure shows the layout of the simscape simulation that was setup and run.

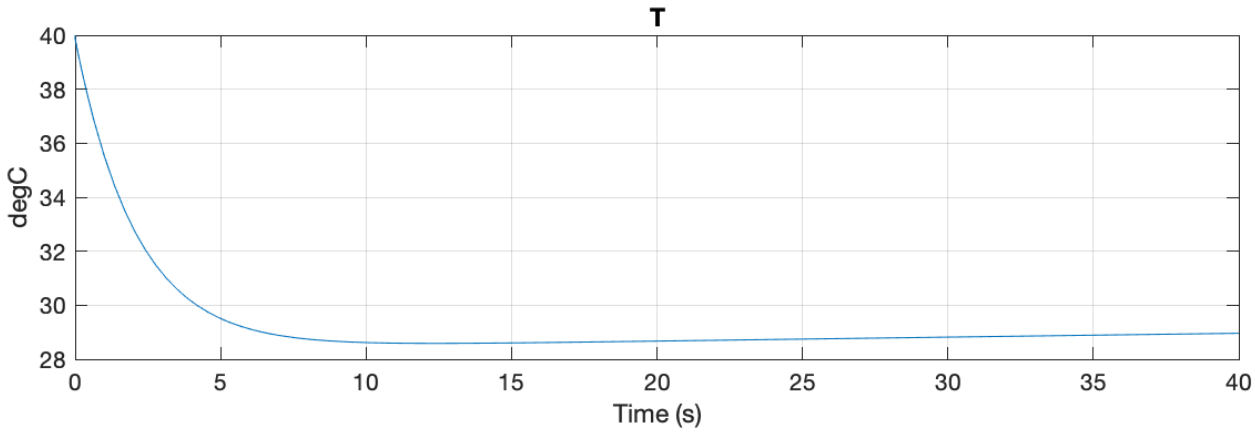
A. The block here the thermal fluid properties are defined including the pressure of the system
B. The block where excess fluid is stored in case it is needed to fill the pipes
C. A mass heat source that provides the heat to the system representing the solar panel
D. This block provides a mass flow rate around the loop to move the fluid around to transfer the heat from the solar panel to the storage device
E. This is used to find the energy transfer from the solar panel to the loop
F. The pipe is used as the heat exchanger for the solar panel to the fluid loop
G. The pipe is used as the heat exchanger for the fluid to the energy storage device
H. This is the graph that shows the energy transfer from the solar panel to the fluid
I. This is used to find the energy transfer from the loop to the energy storage device
J. This is the mass heat block that is acting as the energy storage device
K. This is the graph that shows the energy transfer from the fluid to the energy storage device

Distilled Water

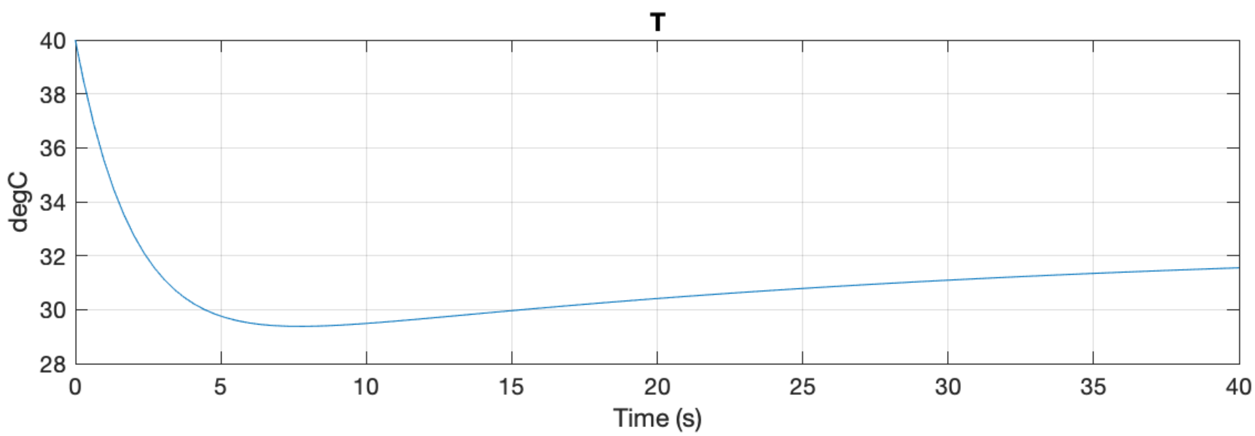
This is the temperature graph of the solar panel with water at 1 atm and 1 kg/s



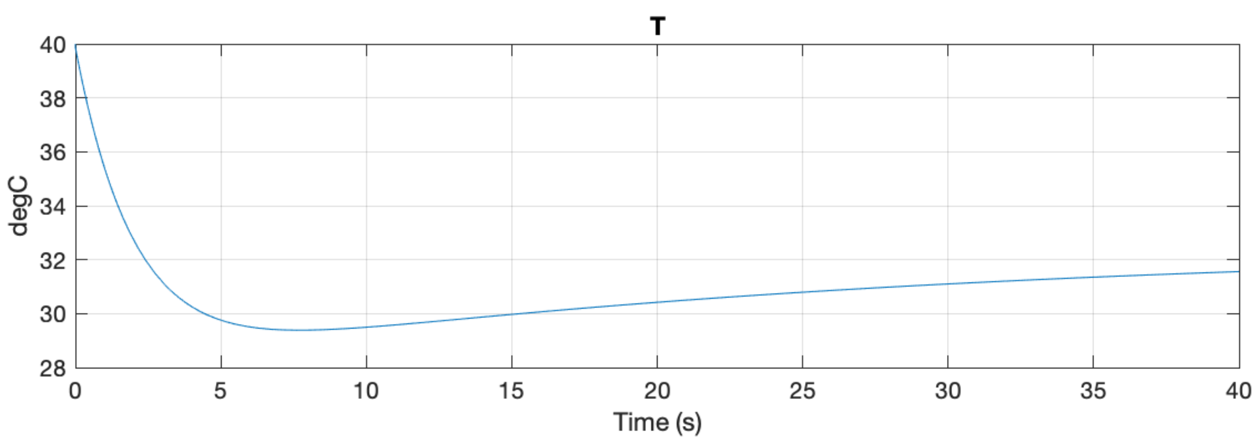
This is the temperature graph of the solar panel with water at 5 atm and 1 kg/s



This is the temperature graph of the solar panel with water at 1 atm and 10 kg/s

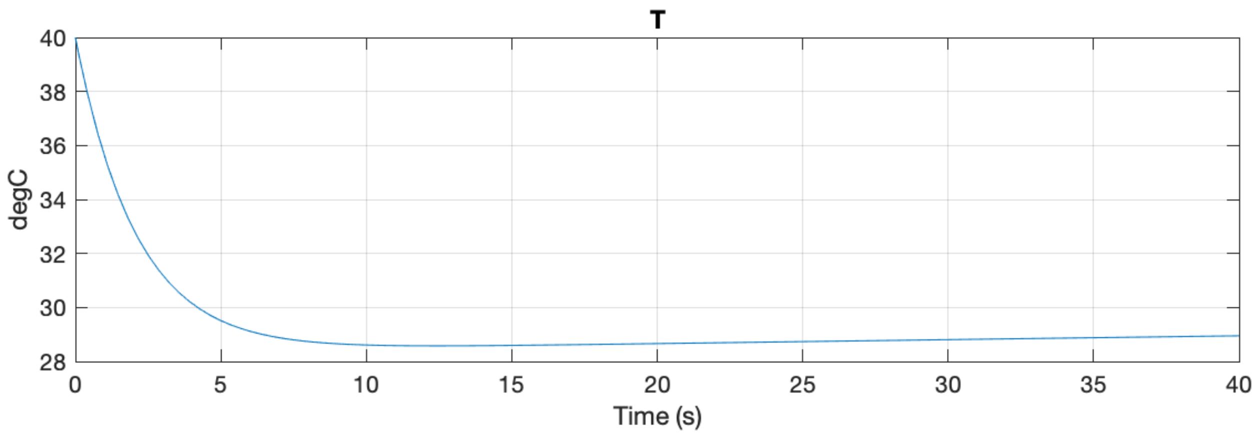


This is the temperature graph of the solar panel with water at 5 atm and 10 kg/s

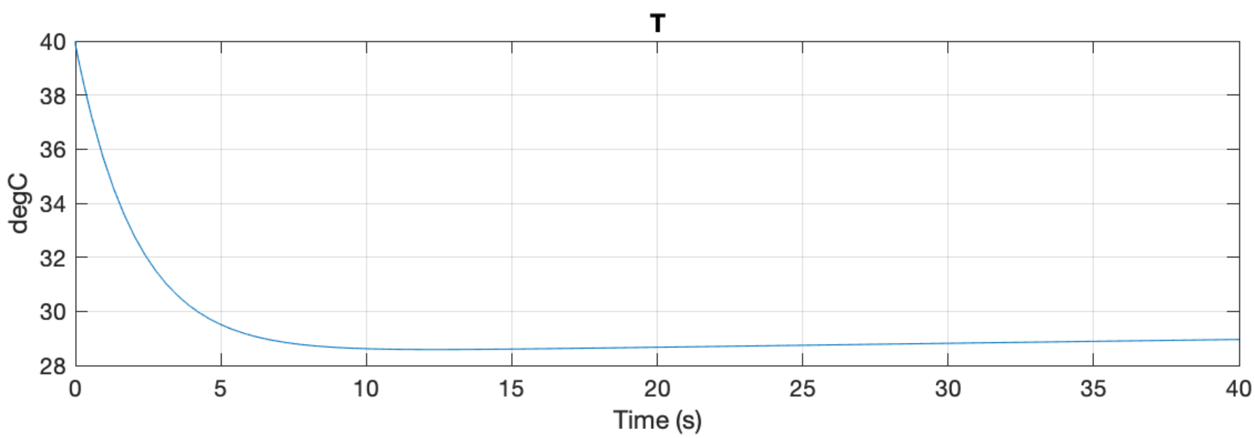


Saltwater

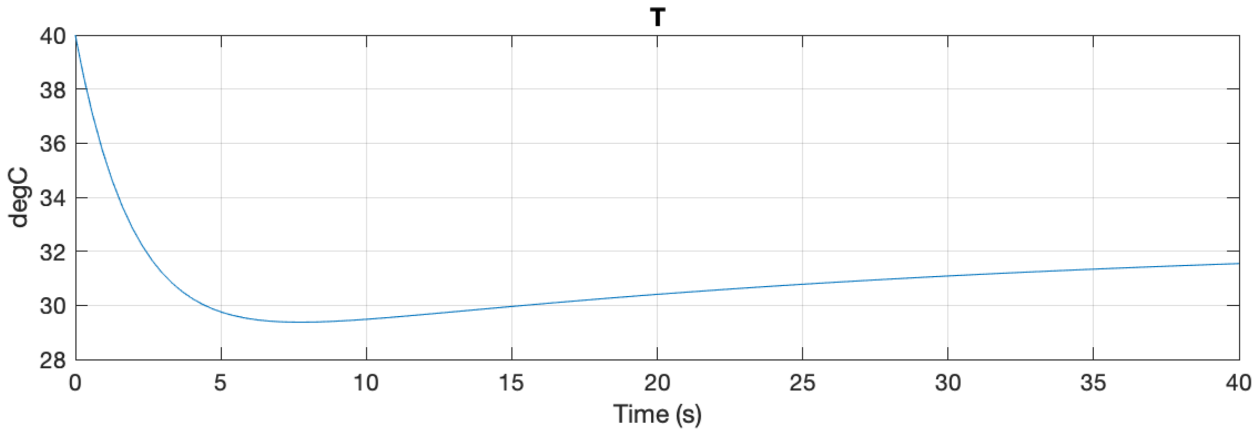
This is the temperature graph of the solar panel with saltwater at 1 atm and 1 kg/s



This is the temperature graph of the solar panel with saltwater at 5 atm and 1 kg/s



This is the temperature graph of the solar panel with saltwater at 1 atm and 10 kg/s

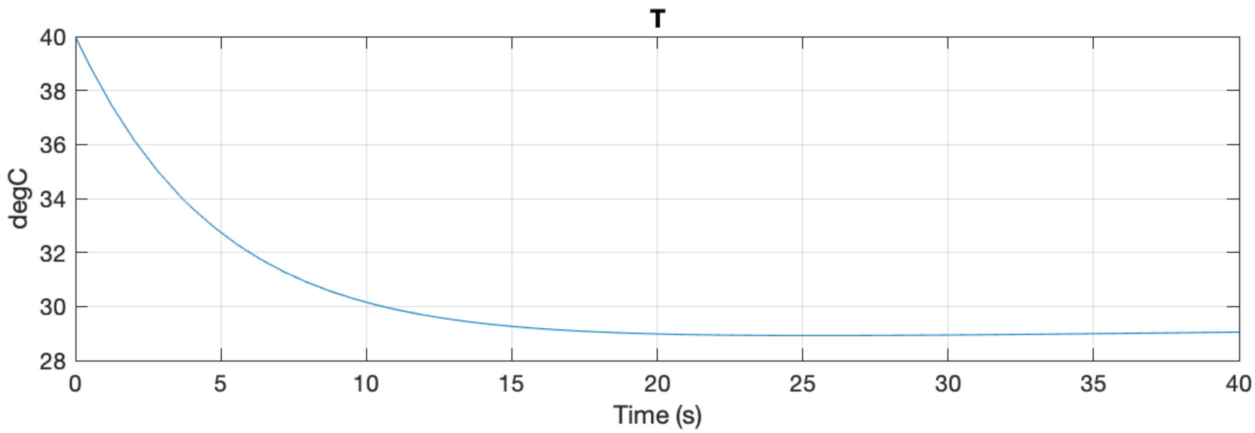


This is the temperature graph of the solar panel with saltwater at 5 atm and 10 kg/s

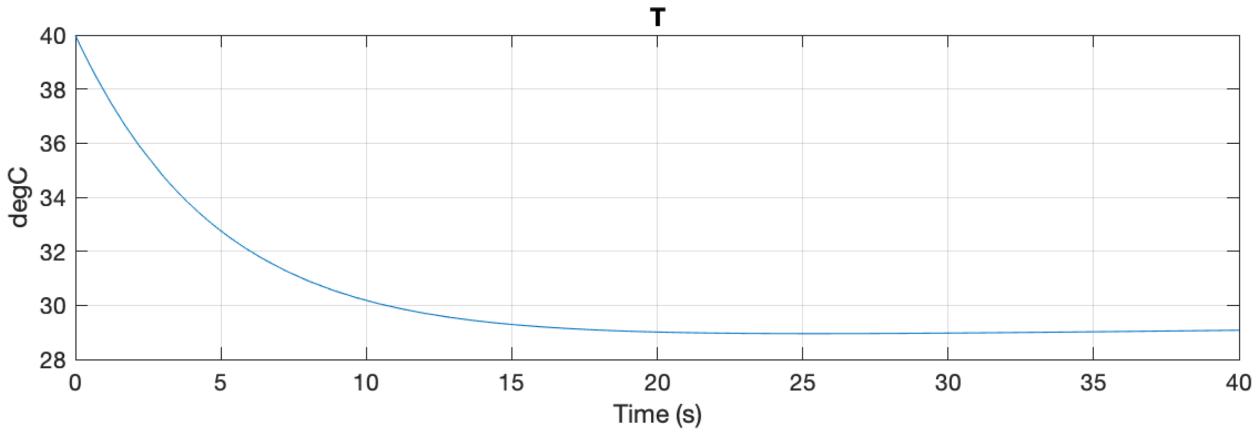
Results were inconclusive/Errored out

Ethylene Glycol

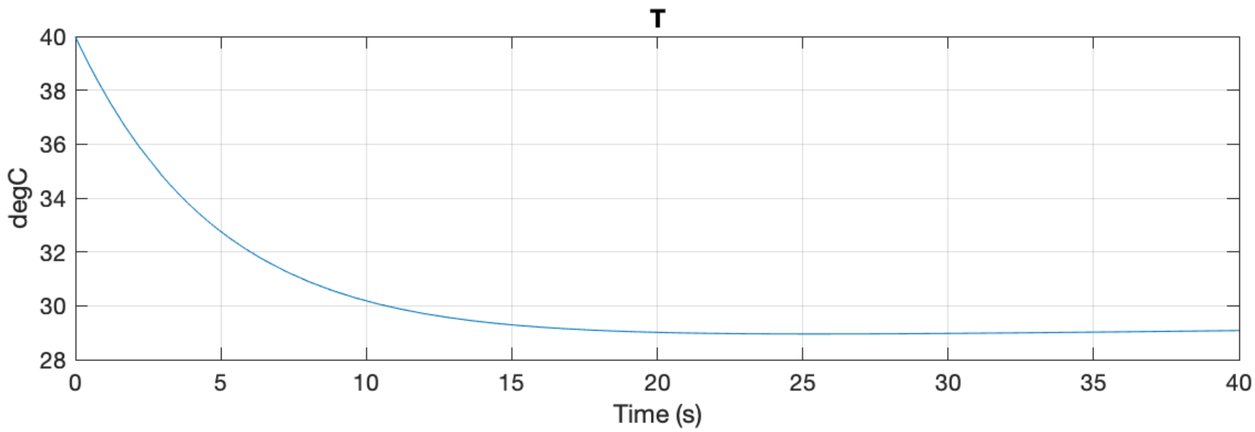
This is the temperature graph of the solar panel with Ethylene Glycol at 1 atm and 1 kg/s



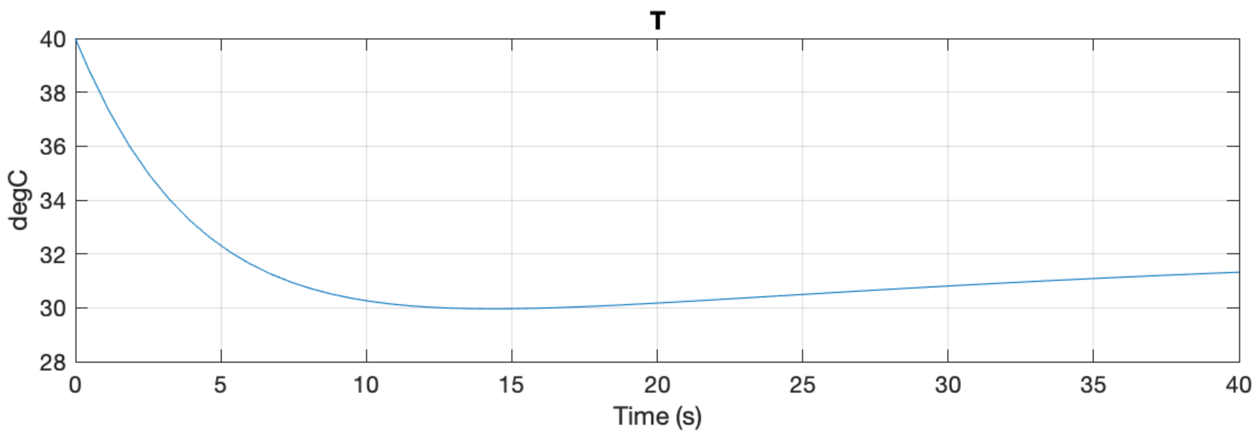
This is the temperature graph of the solar panel with Ethylene Glycol at 5 atm and 1 kg/s



This is the temperature graph of the solar panel with Ethylene Glycol at 1 atm and 10 kg/s

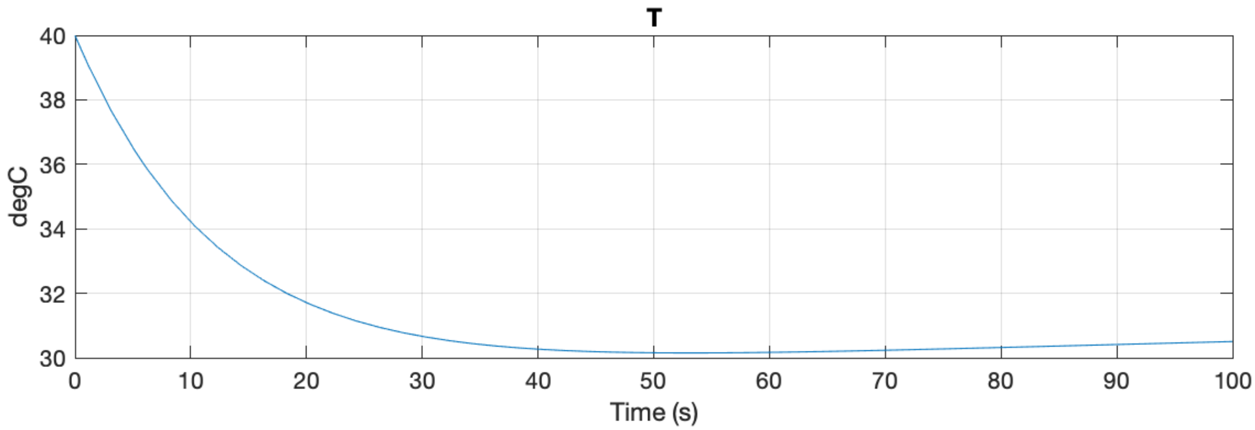


This is the temperature graph of the solar panel with Ethylene Glycol at 5 atm and 10 kg/s

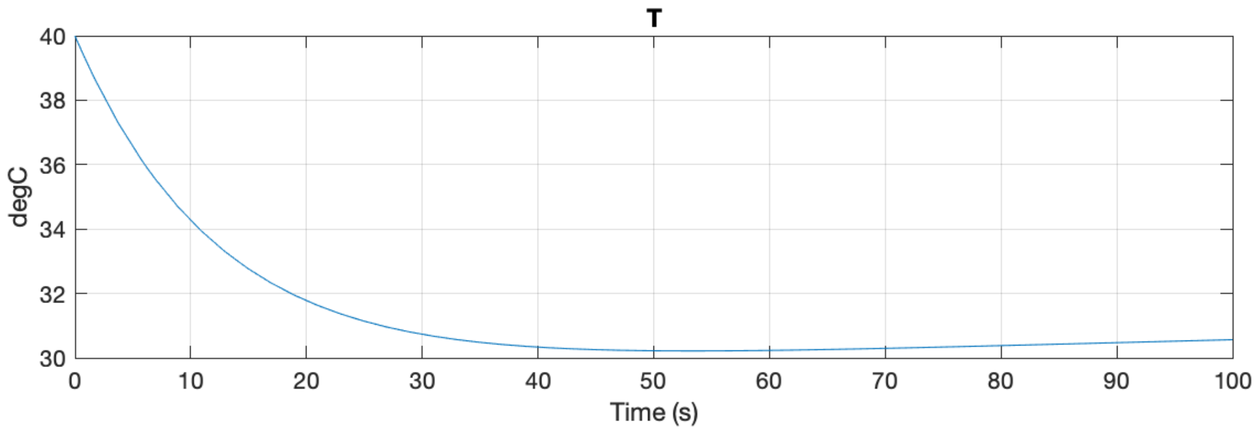


SAE 5W-30

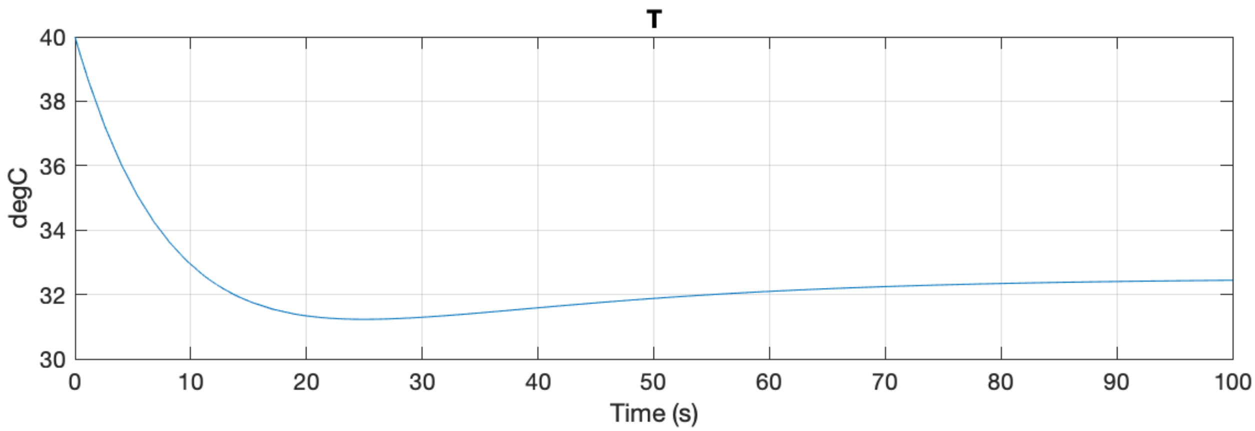
This is the temperature graph of the solar panel with SAE 5W-30 at 1 atm and 1 kg/s



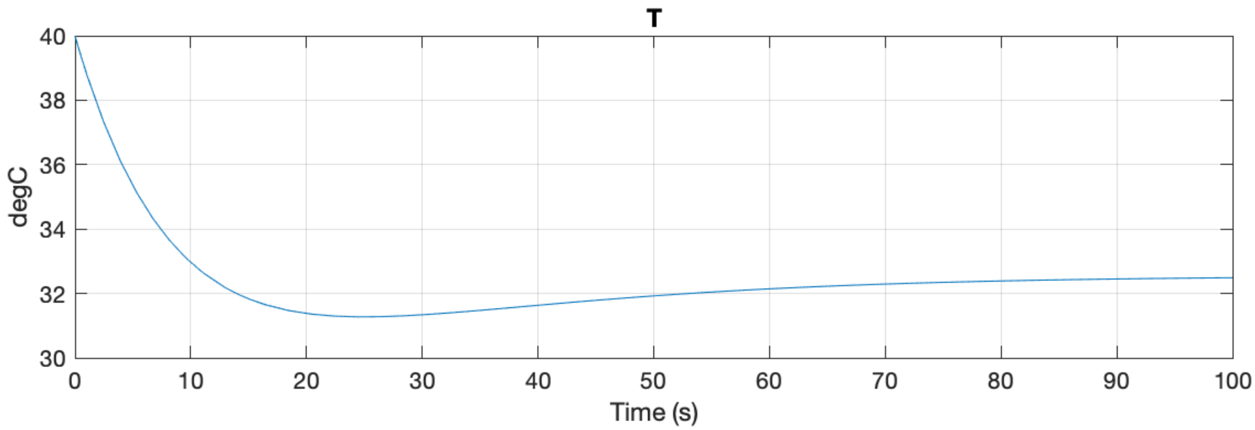
This is the temperature graph of the solar panel with SAE 5W-30 at 5 atm and 1 kg/s



This is the temperature graph of the solar panel with SAE 5W-30 at 1 atm and 10 kg/s



This is the temperature graph of the solar panel with SAE 5W-30 at 5 atm and 10 kg/s



Conclusion

By looking at the results gotten from the graph, we can get the best fluid and the best pressure and mass flow rate that would make the system work the best. We tested four different types of liquids: distilled water, saltwater, ethylene glycol and SAE 5W-30. With each one of these liquids, we tested for four different scenarios where we would vary the pressure and the mass flow rate. The scenarios were 1 atm and 1 kg/s, 5 atm and 1 kg/s, 1 atm and 10 kg/s, 5 atm and 10 kg/s. From these scenarios and different liquids, we determined that the best working fluid was the distilled water at 1 atm and 1 kg/s. We could say this by looking at the time it took the liquid to cool the system the fastest and then keep that temperature for the longest time. Also, this fluid is not corrosive and would work the best in a real scenario. Distilled water is the best to keep the efficiency for the PV/T because it lowers the fastest the temperature of the PV and keeps it at 25 degrees Celsius which we have determined that it gives us the most power out of it.

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