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Performance enhancement of solar module by cooling: An experimental investigation

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Abstract

The study evaluates the silicone oil cooling of the solar module surface. Solar module with maximum power (P_{max}) of 7W was employed for cooling. This paper summarizes the result of an outdoor experiment. The experiments were conducted in batch mode, with the cooling medium spread on the module surface at different thickness from 0mm to 6mm. The performance of the module, throughout the day, for different thickness of the medium is reported. The study also presents a mathematical model, predicting the variation of the maximum power when the module surface is cooled using silicone oil. The results of the equation model are compared and validated with the experimental as well as with results reported in the earlier works. The cooling contributes to appreciable improvement in the module efficiency to above 20%.

Keywords: Module cooling; Silicone oil; Performance improvement; Thickness optimization.

1. Introduction

Energy from Photovoltaic's, though a renewable source, maintains a low efficiency of less than 15%, in its lifelong use. The demand for improving the same is of prior concern as the new era is to depend more on the energy from solar radiation. With the till dated greatest potential, of 10^{16} watts, sun will be one of the everlasting energy supplier when other sources in the country have depleted, but with least utilization.

Temperature reduction is one among the available options for performance improvement of a solar module. Various methods for reducing the temperature are being implemented for the same. A previous study [1] revealed the responses of modules of different materials to temperature change and found temperature rise contribute to quantum of losses. A typical example study, of a thermal analysis model [2] emphasised the role of liquid properties for better absorbance of sunlight. An indoor experiment performed [3] on solar cells, examined the performance of solar cells immersed in liquids under simulated sunlight. The author [3] reported, silicone oil is an alternative option for module cooling. These experiments together summarised significant result, in the improved variation of efficiency as well as V_{oc} with varying thickness of silicon oil. But the above study was limited to indoor simulations. Water spraying techniques [4] on modules, to improve system efficiency, for a water pumping application revealed significant results. Passive techniques are also prominent for cooling, In another study [5] on passive cooling of solar concentrating photovoltaic systems a heat pipe structure is employed for module cooling. A heat sink optimization example for solar cell [6] is analysed using the typical heat sink characteristics for fins of different length. But the sinks, being passive approach, increased the mass and complexity of the system. There has been appreciable works carried out for temperature reduction of module, and study of the module performance to different operating conditions [7-14]. A study [13] on the performance improvement of the panel with cooling and light concentration was carried out, but the study was limited to numerical results and comparison.

Most of the study discusses on the performance of the module while cooling, but there is less concern to the cooling parameters involved. The study here focuses on the cooling of the module surface by spreading the cooling medium on the module surface at different thickness(t). Whenever a cooling medium is employed it reduces the temperature of the module. The thicker the medium the better the cooling. According to the lamberts law, the intensity of transmitted radiation decreases with the increase in path length [3]. So, the increase in thickness of medium has two opposing effects. An attempt is made to optimize the thickness of cooling medium so that power delivered is maximum. Hence, developing a model equation for power output as a function of thickness of cooling medium. The coolant employed here is silicone oil and the experiments were conducted in the outdoor conditions.

2. Materials and methods

2.1 System description

The system consists of a solar module of $7W_p$ power capacity which is surrounded by glass sheets on four sides so that module surface can retain liquid on it. The module properties and other experimental parameters are given in the Table 1. The system set up is as shown in the Figure 1. The silicone oil is spread over the module surface. The fill factor (FF) of the module is assumed to be unaltered at 0.7.

Table 1. The specification and experimental parameters of the solar module employed for the experimental study

Model	USP7
Maximum power (P_{max})	7 Watts
Open Circuit Voltage (V_{oc})	10V
Voltage at maximum power (V_{mpp})	8.5V
Short circuit current (I_{sc})	1A
Current at maximum power (I_{mpp})	0.82A
Tolerance	±10%
No. of cells	18
Dimensions (mm)	320x420x50
Temperature co-efficient	NOCT 45^{o}C
Fill factor (FF)	0.7
Viscosity of silicone oil (mPas)	387

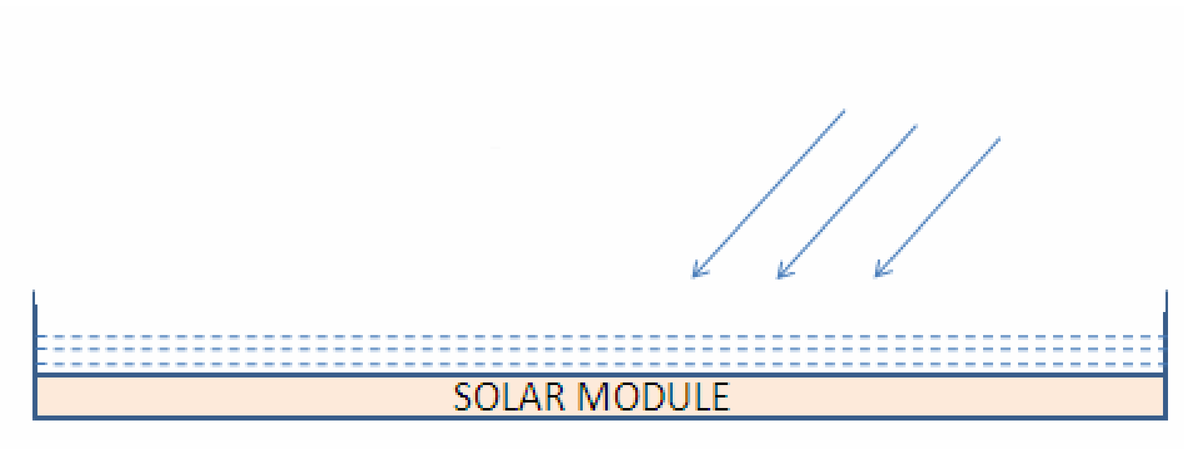

Figure 1. Schematic of experimental setup

2.2 Instrumentation

The experiments were conducted from January to March 2010. The module was kept horizontally with sunlight directly falling on its surface. The global solar radiation incident on a horizontal surface was measured using an Eppley - Precision Spectral Pyranometer with sensitivity, 1mv = 195.3126 W/m^2. The voltage and current was measured by multimeter of ± 0.001% accuracy. The temperature on the module surface was measured jointly using an Infra red thermometer and a k-type thermocouple. All the measurements were taken with reference to a common value of solar radiation. The film thickness was measured using a micro scale ruler. The module temperature is not uniform along the surface. So, a set of nine temperature readings were measured and averaged. The ambient temperature was also recorded. The variation of the insolation, at Trichy location with Latitude N10^o 16` and longitude 78$^o$ 15`, varies from 800W/m^2 to 1000 W/m^2 as shown in the Figure 2.

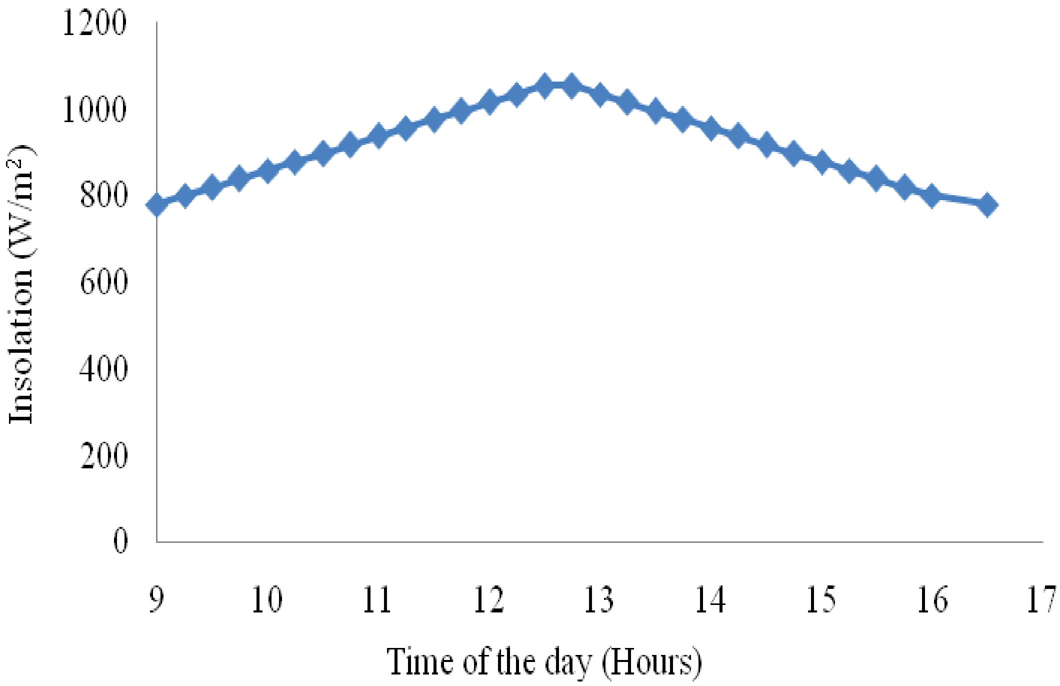

Figure 2. Variation of insolation in Trichy througouht the day,on February 4th 2010

3. Experiment

The experiments were performed on similar sunny days and the effect of wind and other environmental factors were not considered for the study. The coolant medium used was silicone oil. In the first set of experiment the silicone oil was poured on the module surface at 2mm thickness as shown in the Figure 1. The module was kept under sunlight for 7 hours, from morning 9 A.M to evening 4 P.M. The open circuit voltage(V_{oc}), short circuit current (I_{sc}) were measured at specific solar radiation ranging from 600W/m^2 to 1100 W/m^2. The temperature of the module surface was also measured along with the module parameters. The experiment was repeated with different thickness of silicone oil at 3mm, 4mm and 6mm and the measurement parameters were observed. When no medium is used it is assumed to be at 0mm cooling. The evaporation loss for each thickness was measured, and it is less than 0.5%.

4. Equation model for silicone oil cooling

The maximum power delivered by a module changes when cooling is employed. An attempt is made to develop a model for maximum power delivered, while cooling, with the help of the experimental values. The maximum power, at standard condition, delivered by a solar module is given by P_{maxo}, as given in Eq.(1).

$$P_{maxo}=V_{oc}xI_{sc}xFF \tag{1}$$

When the cooling is employed the P_{max} deviates as given in Eq. (2). $\Delta P_{max}(t)$ is the change in Pmax due to cooling at thickness t in Watts. With the help of experimental values a plot is developed for ΔP_{max} and the insolation, for various thickness of the coolant medium. The plots are as shown in the Figure 3. The experimentally derived form of $\Delta P_{max}(t)$ is given in Eq.3.

$$P_{max}=P_{maxo}+\Delta P_{max}(t) \tag{2}$$

$$\Delta P_{max}(t)=[\{(f_1(t)xG)/195.3126\}+f_2(t)] \tag{3}$$

where $f_1(t)$ and $f_2(t)$ are the slope and intercept respectively.The slopes and intercepts for various thickness are calculated from the plot in Figure 4. These values are plotted against the thickness. The function of slope and intercept in terms of thickness t is thus derived from the graph.

$$f_1(t)=[0.011xt^3]-[0.128xt^2]+[0.397xt] \tag{4}$$

$$f_2(t)=[-0.029xt^3]+[0.372xt^2]-[1.267xt]-0.005 \tag{5}$$

Thus the experimentally derived functions for $f_1(t)$ and $f_2(t)$ are given in Eq.(4) and Eq.(5). Equation (3) is further modified, for a module with area A_p, with the above values of slope and intercept to obtain the final model as given in Eq. (6).

$$\Delta P_{max}(t)=[\{(f_1(t)xG)/195.3126\}+f_2(t)]x\lambda \tag{6}$$

where, $\lambda = A_p / 0.1344$

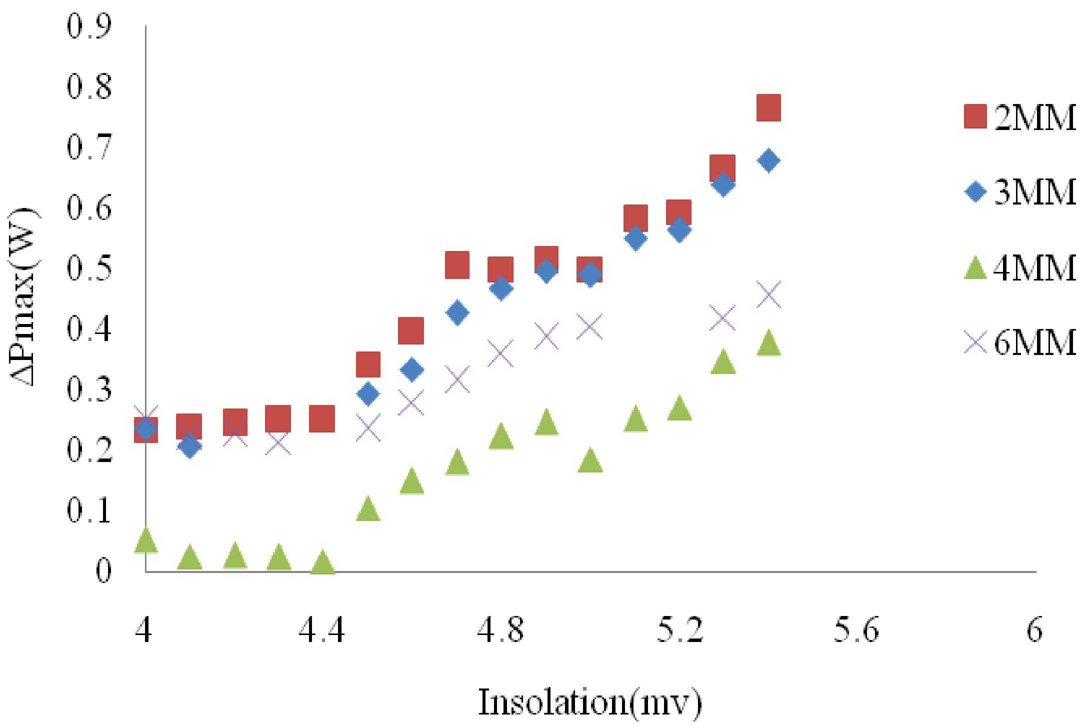

Figure 3. Variation of ΔP_{max} with solar radiation

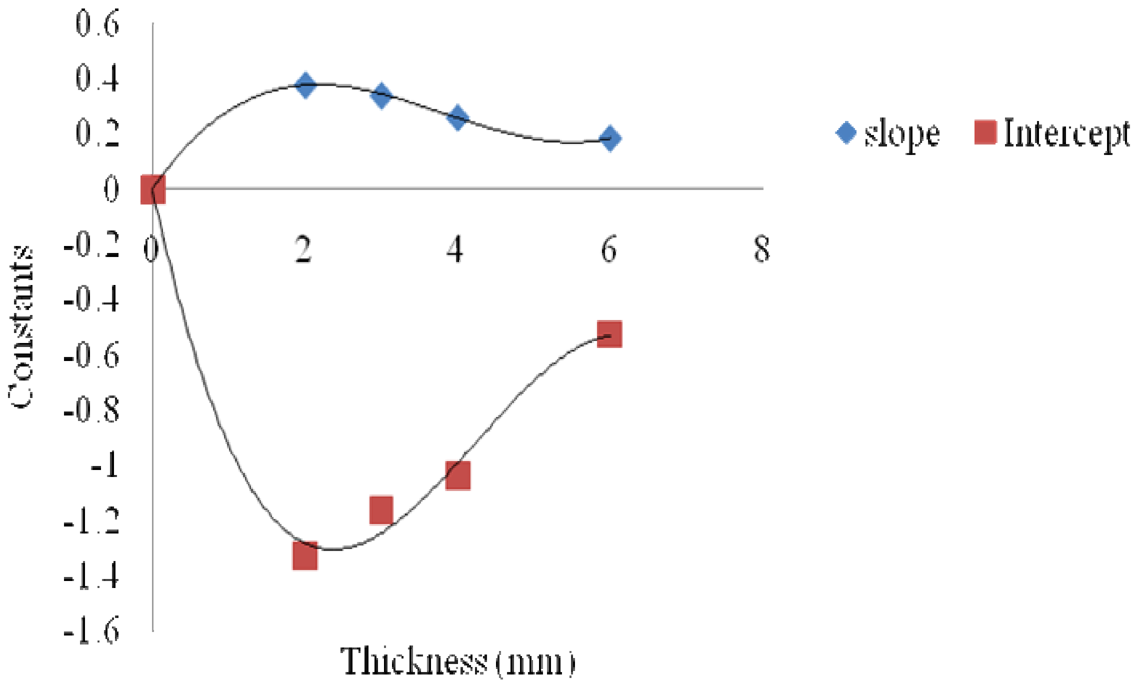

Figure 4. Slope and intercept for different thickness

5. Results and discussion

5.1 Temperature reduction

The photovoltaic cell is prone to thermal degradation when the temperature exceeds above a certain value. And for a crystalline solar cell, the electrical output voltage is a function of the temperature. Due to cooling, the module operating temperatures were significantly reduced in comparison with the module without cooling. A comparative variation for different thickness is shown in the Figure 5. The results show an absolute reduction of 8 degrees to 20 degrees, with varying thickness. The results revealed that there is a percentage temperature drop, compared to 0mm, of 3.92 %, 24.34%, 23.9% and 29.17% for the thickness 2mm, 3mm, 4mm and 6mm respectively. The variation in the temperature with 2mm thickness in the latter half of the day is less steep. This is due to the reason that silicone oil at 2mm was receiving more of solar radiation compared to the other thickness.

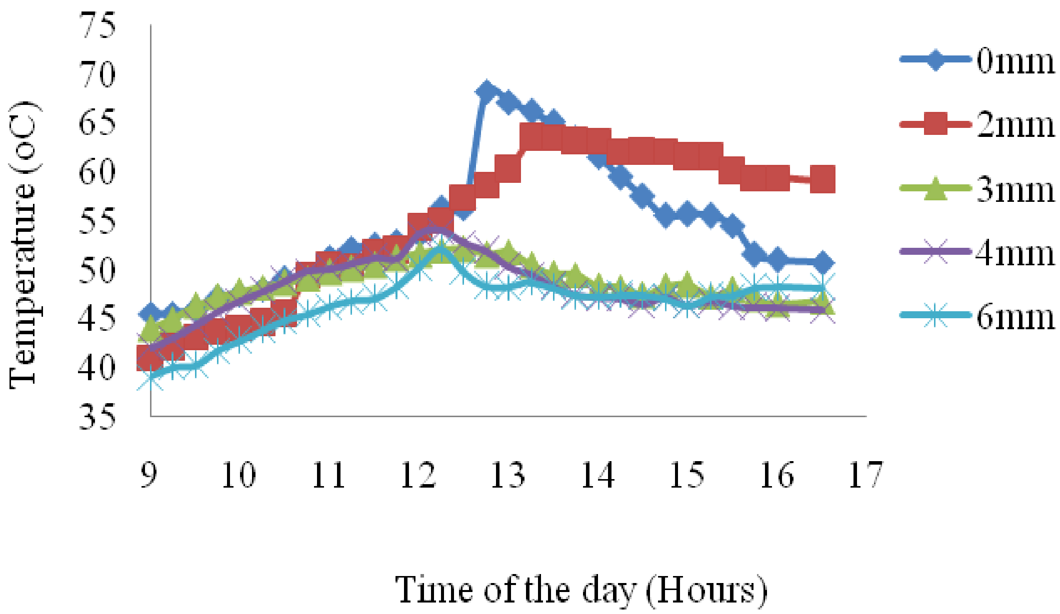

Figure 5. Variation of module temperature throughout the day

5.2 Efficiency variation

The efficiency is a dependent factor on the power generated at an instant. The maximum power, delivered at each instant is calculated from the value of I_{sc} and V_{oc}. A comparative variation of efficiency for different thickness is shown in the Figure 6. The maximum rated efficiency of the module is 5.208% at Standard test conditions. From the experiment it was understood that the value reached only near 2.98% for a non cooling module in the real working conditions. But when cooling was employed, the efficiency value reached above the 3.5% efficiency. It is identified that the 2mm dominated in the efficiency variation curve. The oil immersion improved the maximum efficiency of cooling module to 23.30%, 20.07%, 11.01% and 13.03% respectively for 2mm, 3mm, 4mm and 6mm thickness as compared to value when the module is not subjected to cooling.

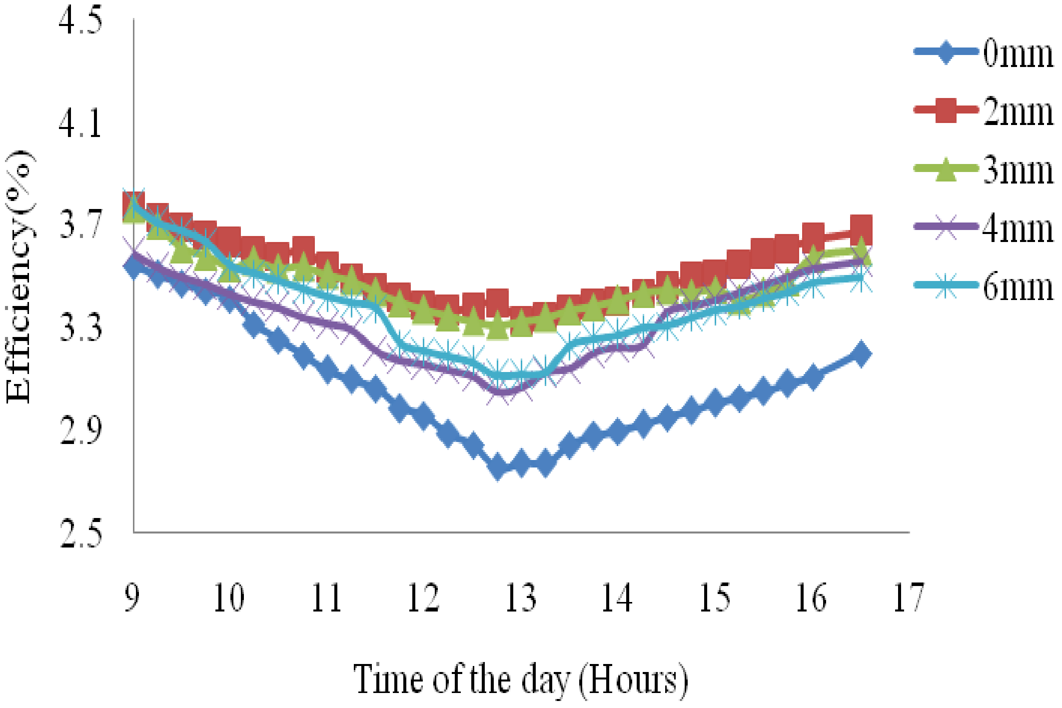

Figure 6. Variation of module efficiency throughout the day

5.3 Maximum power variation

The variation in the maximum power is also realized as a result of cooling. The value of the maximum Power is calculated from the V_{oc} and I_{sc}. Since there is a variation in the value of Voc with temperature, the maximum power also varies. A comparative variation of maximum power for different thickness is shown in the Figure 7. The rated maximum power of the module is 7W. The maximum power attained is almost reaching the value of maximum 3.397 W (at 2mm thickness), while it was at a low of 2.775W at normal operation. The improved variation of maximum power when cooled for different thickness, at maximum insolation, are 23.29%, 20.05%, 10.803% and 13.032 % respectively for 2mm,3mm,4mm and 6mm thickness.

5.4 Thickness optimization

In an attempt to improve the performance, the findings show that there is a considerable improvement in the parameters of keen interest. But, there has been a variation of the parameters over a range of values, for different thickness. The tradeoff between the amount of light absorbed (least optical losses) and the temperature reduction, decides the optimum thickness of reliable operation. From the experimental results it is found that the thickness of interest is 2mm, at which value of maximum efficiency reached peak compared to other thickness. The Figure 8 depicts the variation. The thickness of interest can be further optimized between the value 2mm and 3mm. The equation (3) is validated using the literature experimental readings from earlier work in [3].The calculated values obtained by substituting the values, $G = 999\ W/m^2$ and for module area $A_p = 2.5 \times 10^{-5}\ m^2$ and for different thickness, t = 3mm and t = 6mm are given in Table 2.

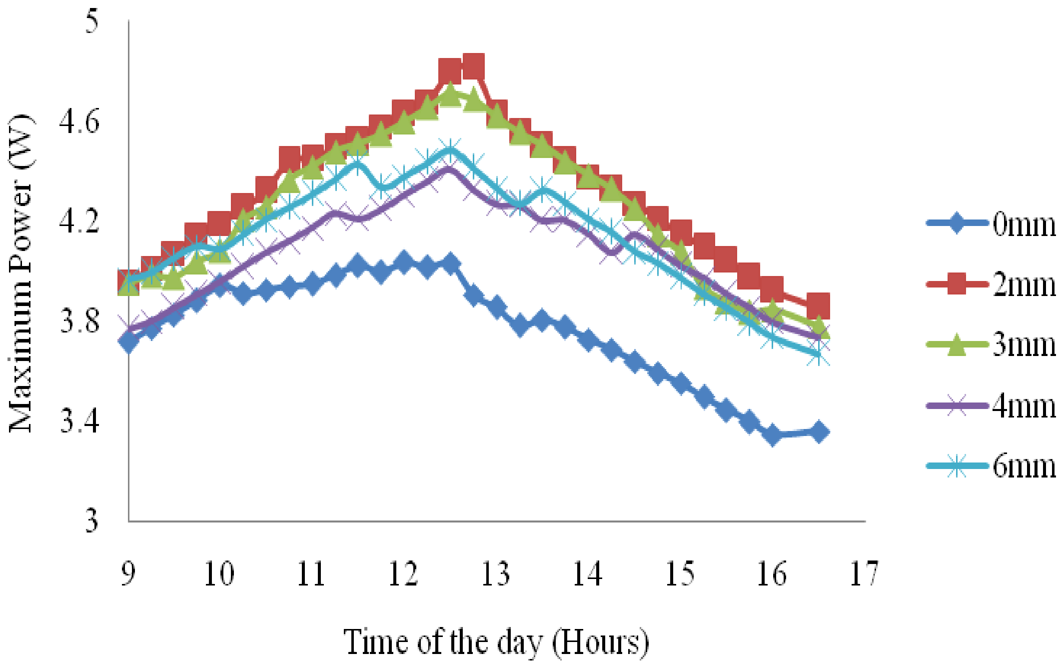

Figure 7. Variation of maximum power delivered by module throughout the day

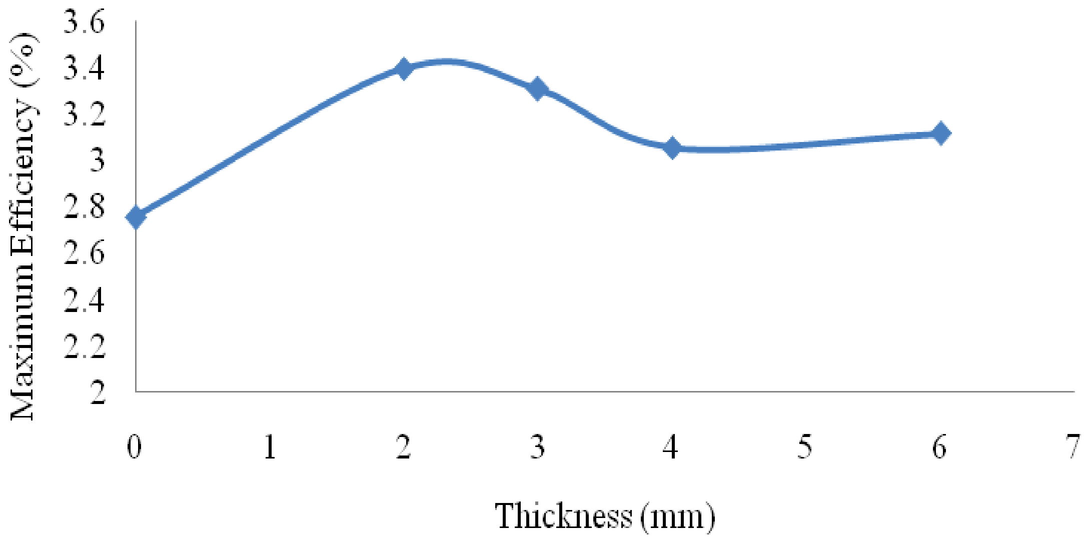

Figure 8. Variation of maximum efficiency (at 957 W/m^2) for different thickness

Table 2. Comparison of model value with the literature value

	Literature value [3] (mW)	Model Value (mW)	% Error
3mm	3.79067	3.74038	1.34
6mm	3.71999	3.70566	0.3867

5.5 Comparison of model values with experimental values

The P_{max} values are calculated for different thickness using the Equation (3) and it is compared with the experimental value. The variation in percentage error for different values of solar radiation is as shown in the Figure 9. The variation of the model value from the experimental value is always less than 5%.

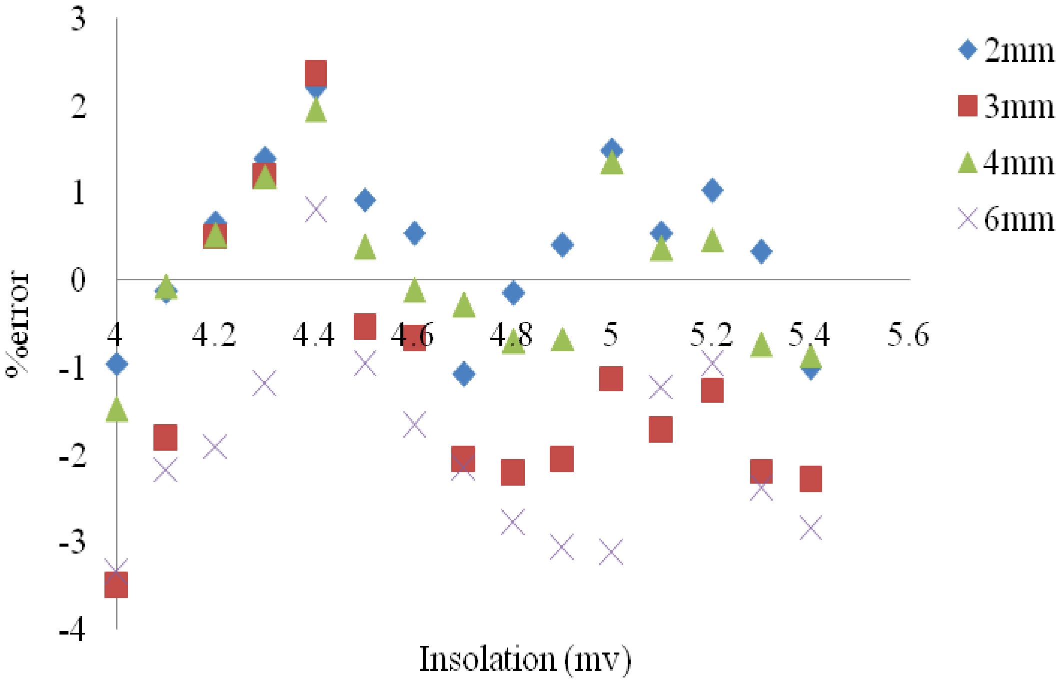

Figure 9. Percentage error for model value and experimental value for different thickness throughout the day

6. Conclusion

The Standard Test Condition (STC) which specifies the module surface temperature to be 25 °C is not practically possible in the real time implementation of solar projects. This study examined the performance of a 7W amorphous silicon photovoltaic module, with a quantity of silicone oil spread over its surface. A model was developed for the maximum power of the module, specific to the module rating and thickness. The experimental results suggest a way to improve the performance of the module by cooling of the solar modules by silicone oil thereby improving the efficiency by 23.30% for 2mm thickness. The efficiency increases with thickness and then drops at higher thickness. The thickness of interest, while cooling, was found to be between 2mm to 3mm which can be again explored for precise optimization. The model value and experimental value were compared and the error was found to be below 5%. Also the model equation was validated with the simulated results and they are in good agreement. The maximum power delivered also increased by 23.29%, when cooling was employed. Cooling also maintains the temperature to a certain limit, between 45°C to 55 °C, thereby avoiding long term thermal degradation.

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