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Analysis of the Effect of Delay Time and Type of Coolant Media with the Spray Method on the Back Surface of PV Panel

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Pathur Razi Ansyah[1], Muhammad Hendrawan Septian Hartoyo[1], Akhmad Ghiffary Budianto[2], Gunawan Rudi Cahyono[2], Rachmat Subagyo[1]

[1]Department of Mechanical Engineering, Universitas Lambung Mangkurat, Indonesia
[2]Department of Electrical Engineering, Universitas Lambung Mangkurat, Indonesia

Corresponding author:
Pathur Razi Ansyah
Universitas Lambung Mangkurat
Email: pathur.razi@ulm.ac.id

Abstract

Sunlight can be harnessed as a clean and renewable energy source using solar cells and the photovoltaic process. However, relying on direct sunlight exposure can increase solar cell temperatures and negatively impact performance. This research aims to maintain cell efficiency by exploring the effectiveness of spraying coolant media on the bottom surface of panels through three timed intervals (10, 20, and 30 minutes) using three different media (A, B, and C). Each spray application lasts for 1 minute. Analyzing the test results with Minitab18 software with full factorial design will identify the most effective treatment for maintaining performance. Based on the results of the experimental test, coolant A with a 10-minute delay spraying time has a maximum power of 52.89 Watts, a temperature of 48°C, and an efficiency of 5.69%. Response Optimization using Design of Experiment (DOE) Full Factorial shows an optimal response with coolant A and a 10-minute delay spraying time with the lowest temperature at 49.3°C, maximum output power at 46.87 Watts, and efficiency at 5.61%. Moreover, Tukey Krammer test result provides an information about 10-minute delay spraying time has a better performance to reduce the PV panel temperature compared to 30-minute delay spraying time by 3.94 °C.

Keywords: *Solar panel, solar panel cooling, photovoltaic, software engineering, renewable energy*

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INTRODUCTION

Renewable energy originates from various issues of dependence on fossil fuels, climate change, economics and policy, and energy sustainability systems. Renewable energy is energy produced from natural resources and can be renewed (wind, water, biomass, solar energy, marine energy, etc.). On the contrary, non-renewable energy is only available in limited quantities and cannot be renewed (petroleum, coal, gold, silver, etc.) [1]. Solar energy is one of the developments in renewable energy as a clean alternative energy source. The solar panel is a device that converts energy into an electricity source and is used to generate solar energy. The process of converting solar energy into electrical energy is carried out with the help of photovoltaics on solar cell devices [2]-[3]. Solar cells, also called photovoltaics, consist of an arrangement of semiconductor materials that induce electricity [4]. Generally, forming electrical energy through solar cells comes from the photon content of sunlight, which is absorbed by the semiconductor material; the negative and positive charges of the material will experience an exchange of places, producing electrical energy in the area that limits the material [5]. However, there are several obstacles to applying this energy in its use. One obstacle that occurs in the application of this energy is the temperature increase of the solar panels as a result of continuous and continued exposure to direct radiation; according to Z. Aqli [6], when the temperature increases, the semiconductor band gap temperature decreases, thus increasing the value resistance and slowing down the transfer of electrons slows down. According to S. Safrizal [7], solar cell performance is deficient because the current that will flow depends on the photovoltaic effect in absorbing solar energy.

To overcome the problems occurring in the application of solar energy, a cooling system should be added to control the temperature of the solar panels to optimize their conditions and produce the best and most constant output power. One method for cooling solar panels is by spraying coolant onto the solar panels' surface. The cooling system can use water, be it seawater, mineral water, or water spray [8]. However, applying cooling by spraying coolant affects the output power. According to I. B. G. Widiantara and N. Sugiartha [9], the cooling effect on solar cells can work well, but from the perspective of energy use efficiency, it could be more profitable. It was also found that cooling on solar panels is not practical, considering that electrical power is used to turn on the cooling system before the solar cells start to be used. According to W. M. Setiavi, et al. [10], the water-cooling system that flows over the surface of the solar panels succeeds in reducing the temperature of the solar panels. Yet, the flow of water over the surface of the panels minimizes the light received so that it cannot increase the power of the solar panels; further in his research, according to W. M. Setiavi, et al. [10], the cooling effect on solar panels can indeed reduce the temperature and increase their efficiency. Still, if the cooling system is applied to the solar panels for too long, the intensity of the light received can be reduced. Therefore, the power of the solar panels stays relatively high.

While the performance results have some limitations, the application of this system offers several advantages. According to S. Nižetić, et al. [8], cooling solar panels with a surface spraying system can significantly improve performance and reduce surface temperatures by up to 50%. H. Bahaidarah, et al. [11] also stated that implementing a liquid cooling system could reduce temperature by up to 20% and increase efficiency by 9% with an increase in collector energy up to 4 times greater, which is also in line with research conducted by A. Bening and D. Monika [12], which concluded that the solar panel cooling system greatly influences the output voltage and power produced by the solar panel; when the temperature is colder the output voltage and power increase when compared to before cooling. This research aims to maintain cell efficiency by exploring the effectiveness of spraying coolant media on the bottom surface of panels through three timed intervals (10, 20, and 30 minutes) using three different media coolants. The experimental design will identify the most effective treatment for maintaining performance. This will help to collect the data about cooling system with spraying cooling media not only on the PV panel surface but also on the bottom surface on the small scale.

METHODS AND ANALYSIS

This research uses a quantitative analysis research method, which focuses on experimental studies, data collection and calculation, data assessment, and data processing in such a way. The research writing design method will use a completely randomized design, which, according to A. S. Rahmawati and R. Erina [13], explains that a completely randomized design is a complete randomization pattern of variables, so there are no restrictions in controlling with the same treatment. Applying this method will lead to an analysis of variance (ANOVA) for analyzing variables totaling more than two populations in independent groups.

Experimental testing of the addition of a liquid cooling system using the spray method on the bottom surface of the solar panel was carried out under direct exposure to solar radiation. According to E. B. Agyekum, et al. [14], a cooling system with the spray method on the solar panel surface can reduce the average temperature by up to 23.55°C. Cooling techniques using spraying coolant on the solar panels' surface can increase performance values and reduce the surface temperature of solar panels up to 2 times. According to A. Bening and D. Monika [12], the cooling system on solar panels dramatically influences the performance of solar panels; when the temperature of the solar panels is low, the performance produced by the solar panels will increase compared to the performance of solar panels without cooling.

The coolant will be sprayed for 1 minute at each time interval used. The spraying time interval was varied by 3 with variations of 10-minute spraying pause, 20-minute

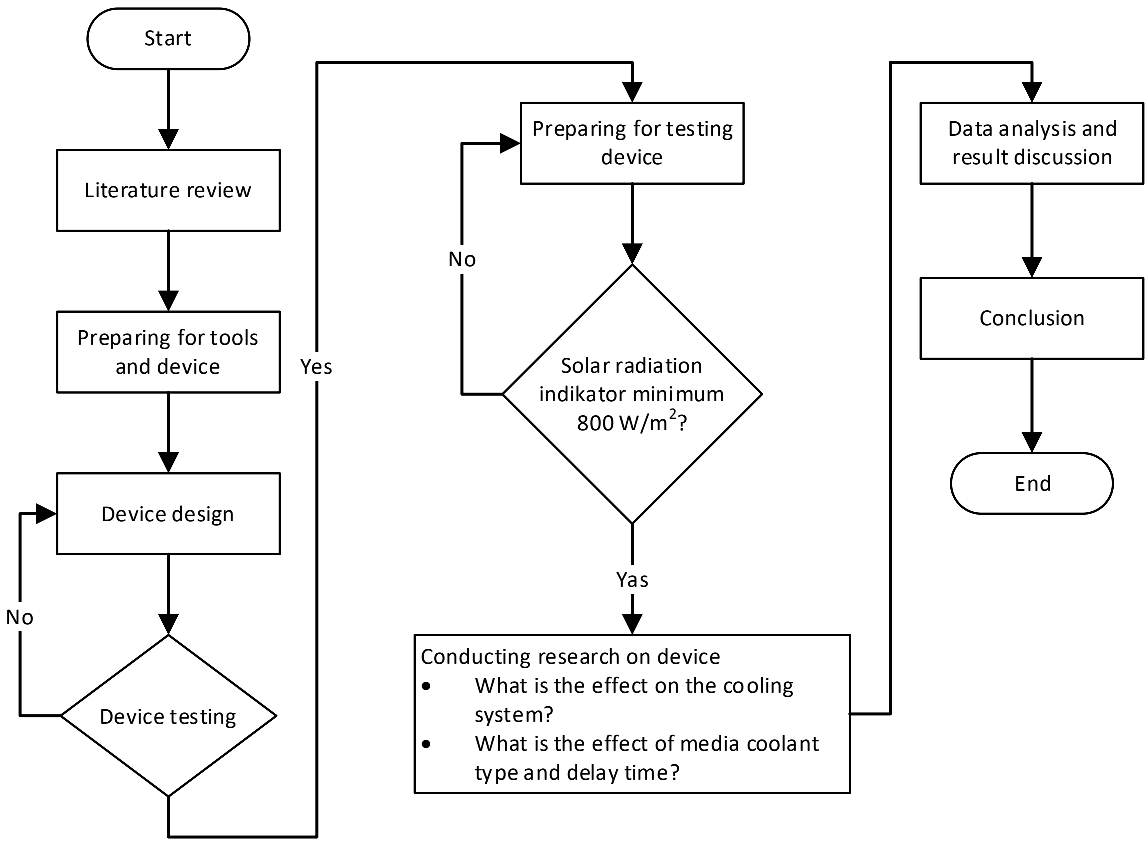

Figure 1. Research implementation scheme

spraying pause, and 30-minute spraying pause. The long period for spraying coolant will affect the performance of solar panels; the longer the spraying time is, and the more frequent the spraying breaks, the better (increased) performance of the solar panels [15]. The cooling media used also varied with the number of applications of 3 types (A, B, and C). This aims to test the content of the compounds that make up the liquid cooling media and how they influence the performance of the solar panels. Testing the compound content in each type of cooling media was carried out using the GC-MS method. An illustration of the research method can be seen in Figure 1.

Research Design

This research commences by conducting a literature study following the discussed topic. This aims to obtain various supporting data from previous research to determine the appropriate research concept, examine the basic theory supporting the implementation of the research, and benchmark the development of research stages that can be used as a reference for further development.

Furthermore, based on the basic concepts obtained, various supporting components for conducting research can be prepared and adapted to conditions and practices in the field, resulting in complex data.

Device Design

Device design is the most crucial stage for carrying out manufacturing preparations for data collection devices and preparation for providing tools and materials used to support the implementation of data collection in the field; thus, the variable data obtained follows the research objectives. Undoubtedly, this design aims to reduce errors in the final design of a test device before resuming testing [16].

Before manufacturing the device, a device design is carried out with the assistance of engineering design software to determine dimensional measurements and calculate

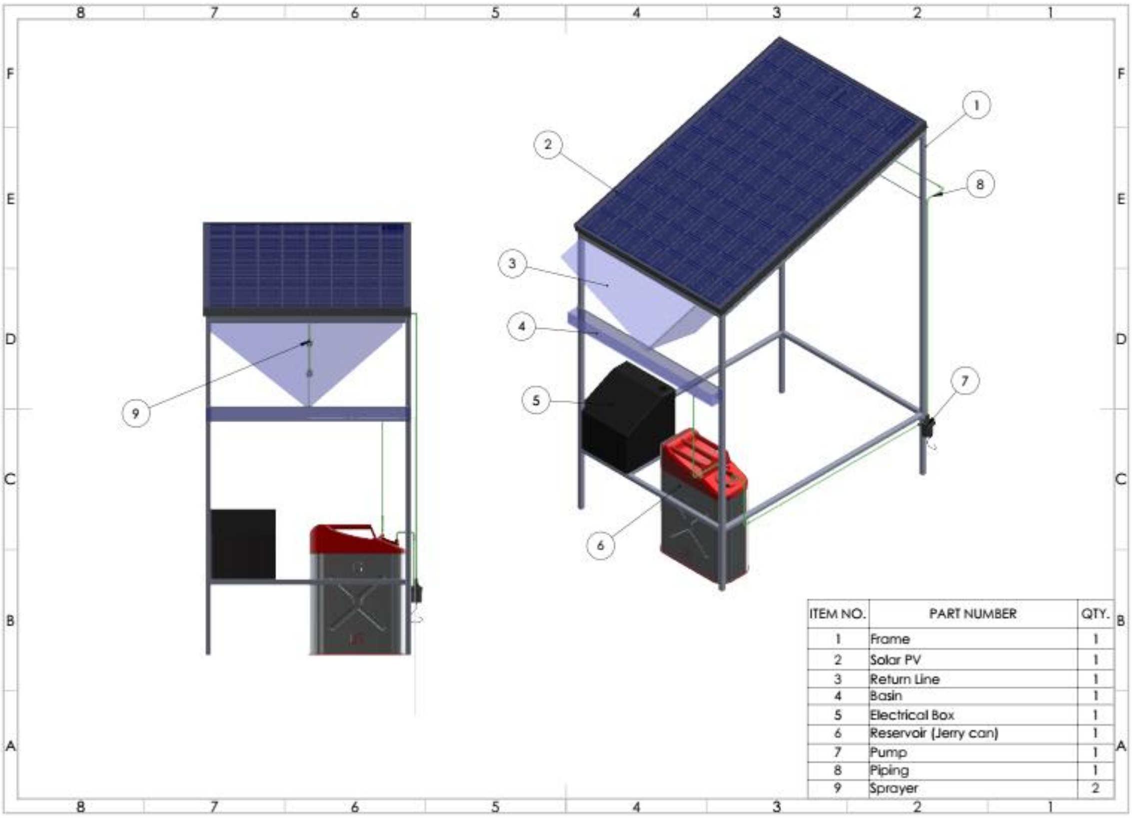

Figure 2. Device design

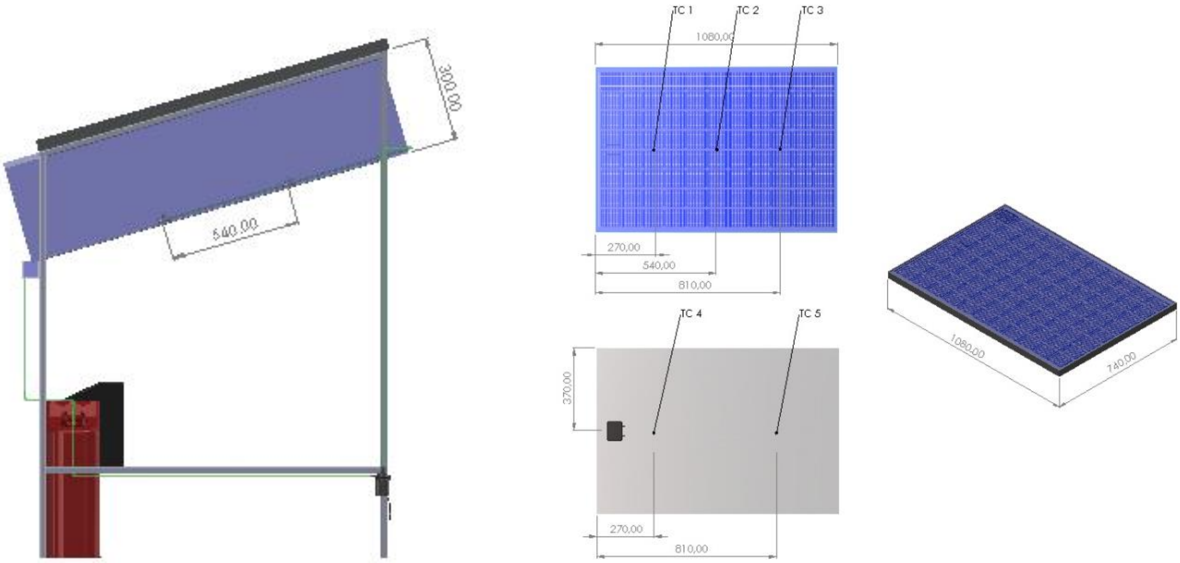

Figure 3. Position of nozzle and thermocouple

Table 1. Data layout Properties of coolant by GC-MS

Type	Chemical Properties	Value
A	Dodecanoic acid, 1, 2, 3 – propanetriyl ester	97,455%
	Dodecanoic acid, ethenyl ester (CAS) Vinyl	1,787%
B	Hexanoic acid, 2 – ethyl – (CAS) Ethylhexoic	17,932%
	Hexanoic acid, 2 – ethyl – methyl ester	2,50%
	Eicosanoic acid, 1, 2, 3 – hydroxyethyl ester	7,816%
	Dodecanoic acid, 1, 2, 3 – propanetriyl ester	60,436%
	Eicosanoic acid, 2 – hydroxyethyl ester	5,785%
	Dodecanoic acid 1 (hydroxymet)	4,293%
	Hexadeconic acid, 2 – hydroxyethyl ester	1,685%
C	Octanoic acid (CAS) caprylic acid	12,783%
	Dodecanoic acid, 1, 2, 3 – propanetriyl ester	83,417%
	Octanoic acid, 1, 2, 3 – propanetriyl ester	1,315%
	Dodecanoic acid, ethenyl ester (CAS) vinyl	2,481%

the amount of material needed during the manufacturing process to streamline quantity and production costs. Device design aims to produce a blueprint as a reference for the manufacturing process. After completing all design stages, the following step was to apply the design to the manufacturing process. In designing the device used in this research, a 100 WP tesla solar panel 780x510x35 (mm), DC water pump, thermocouple, data logger, and nozzle were used. The device design that we used in this research, can be seen in Figure 2.

Seven thermocouples were used, with 5 points on the solar panel and 2 points on the cooling media path entering and leaving the cooling system. The distance between the thermocouples on the solar panel is shown in Figure 3. We used 2 nozzles with a distance between the nozzles of 540mm, and the distance between the nozzle for spraying the cooling medium towards the solar panel was 300mm. Because the cooling medium was sprayed at the bottom of the solar panel, it was necessary to collect and return it to continue circulating for cooling. Meanwhile, the solar panel would be positioned at 30° facing directly toward the sun's direction because, according to S. Samsurizal, et al. [17], the solar panels can work more optimally in that position.

Device Testing

This testing stage includes trial and error, improvement, and data retrieval. *Trial and error:* at this stage, devices were tested for the function of all components to prevent malfunctions that could affect the research data's results. *Repair: s*hould it be felt that the device is malfunctioning, repairs or even replacement of components were carried out; thus, the data collection process can follow the research objectives. *Data Collection:* the data collection process was carried out after checking the overall component function. To obtain constant data, data can be collected with a standard solar radiation intensity limit of >800W/m^2 and at 10.00-15.00.

Data Processing

At this data processing stage, DOE (Design of Experiment) was used with two variable factors and three levels of testing, therefore using time lags of 10 minutes, 20 minutes, and 30 minutes, as well as the application of cooling media types A, B, and C would produce a total 9 data experiments for further research. From 9 trials, the average data for each test was taken. Thus, the data processing was as follows:

The coolant media was tested using the GC-MS method to determine the compound content of the various types of coolant media used. The GC-MS method for liquids is the use of Gas Chromatography-Mass Spectrometry (GC-MS) to analyze the chemical compounds contained in a liquid sample. This method combines two analytical techniques, namely Gas Chromatography (GC) and Mass Spectrometry (MS), to separate, identify, and quantify the chemical components in the liquid sample. Next, the experimental data amounted to 60 per experiment, carried out nine times. Thus, the data from this research was calculated as an average to simplify and assumed to have a constant value. Lastly, the research data were processed using the ANOVA method, and a posthoc test (Tukey-Krammer) was carried out with the significance level set at 5% to determine the influence of 2-factor variables (time lag 10 minutes, 20 minutes, 30 minutes, and type of coolant media A, B, C) to 3 responses (solar panel temperature, output power, and efficiency).

Table 1 shows the chemical composition of the coolant media used in this study. The coolant media used has a high content of propanetriyl ester, greater than 60%. The presence of propanetriyl ester can provide thermal properties that support the fluid's ability to absorb heat effectively, which is important for cooling system efficiency. Coolant media A has the highest content of propanetriyl ester, while coolant media B contains an additive for anti-freeze, resulting in a propanetriyl ester content of only 60%. Meanwhile, coolant media C contains an additive for anti-corrosion.

RESULTS AND DISCUSSIONS

Experimental

The experimental test results would show the up and down of the temperature graph and the solar panel's performance. To produce constant calculations, the test result data would be processed; thus, it became the average value of each variable observed. This test refers to research conducted by P. Simatupang [18] and Y. Rakhmadanu, et al. [19], which state that the highest temperature during the day ranges from 35°C-42°C. Therefore, this observation would be carried out at 10.00-15.00 with the condition of data collection that the variable of solar radiation intensity must be >800W/m^2 to ensure that the observation results are constant (not significantly different). The collected data can

Table 2. Average result for cooling system

Coolant	Surface Area	Delay	Avg. Voltage	Avg. Current	Avg. Power	Avg. Radiation
A.	0,69 m^2	10 min	19,80 V	2,15 A	42,39 W	1081 W/m^2
		20 min	19,83 V	2,34 A	46,57 W	1214 W/m^2
		30 min	19,39 V	1,75 A	34,12 W	1036 W/m^2
B.	0,69 m^2	10 min	19,30 V	2,27 A	43,61 W	1193 W/m^2
		20 min	19,32 V	1,66 A	31,71 W	1051 W/m^2
		30 min	19,58 V	2,33 A	45,70 W	1123 W/m^2
C.	0,69 m^2	10 min	19,95 V	2,09 A	41,55 W	1090 W/m^2
		20 min	19,77 V	1,64 A	32,46 W	952 W/m^2
		30 min	19,95 V	2,28 A	45,46 W	1192 W/m^2

Table 3. Experimental test results of the variables observed

Input power			**Max power**			**Efficiency**		
Coolant	Delay	Value (W)	Coolant	Delay	Value (W)	Coolant	Delay	Value (%)
A	10 min	745,89	A	10 min	52,89	A	10 min	5,69
	20 min	837,32		20 min	53,54		20 min	5,59
	30 min	714,64		30 min	43,14		30 min	4,90
B	10 min	823,41	B	10 min	51,38	B	10 min	5,50
	20 min	725,07		20 min	42,12		20 min	4,53
	30 min	775,11		30 min	56,73		30 min	5,94
C	10 min	752,04	C	10 min	49,56	C	10 min	5,54
	20 min	656,59		20 min	39,06		20 min	4,93
	30 min	822,16		30 min	50,69		30 min	5,53

be seen in Table 2.

All the observation data in Table 2 were processed into an average, which was then calculated to determine the value of the test variable. All the experimental have met the requirement which radiation intensity must be >>800W/m^2. Statistical calculations were performed using statistical software to assess the effect of the test variable on the solar panel's performance.

Input power is the calculation between radiation intensity and the surface area of a solar cell, which is formulated as follows:

$$P_{in} = I_r \times A \tag{1}$$

where P_{in} is Input power from radiation (W), I_r is Solar irradiance (W/m^2) and A is surface area of the solar panel (m^2).

Maximum power is the peak value of the output that can be produced by a solar cell, which can be formulated as follows:

$$P_m = V_m \times I_m \tag{2}$$

where P_m is maximum output power (W), V_m is maximum voltage (Volt), and I_m is maximum current (Ampere).

Efficiency is the percentage of sunlight that it can convert into usable electricity, which is formulated as follows:

$$\eta = \frac{V_p \times I_p}{E \times A_p} \qquad (3)$$

where η is efficiency of solar panel (%), V_p is panel voltage (Volt), I_p is panel current (Ampere), E is solar irradiance (W/m2) and A_p is surface area of the solar panel (m^2).

The following is an example for calculating performance using equation (1), (2) and (3) with a time lag of 10 minutes and cooling media type A:

$$P_{in} = 1081 \times 0{,}69 = 745{,}89\ Watt$$

$$P_m = 21{,}33 \times 2{,}48 = 52{,}89\ Watt$$

$$\eta = \frac{19{,}90 \times 2{,}15}{1081 \times 0{,}69} = 5{,}69\%$$

The following is a table of experimental test results of the variables observed at each delay spraying time and application of the type of cooling media. Table 3 presents the results of an experiment investigating the impact of different coolants and delay times on various parameters of a PV panel cooling system. Overall, Coolant A with a 20-minute delay appears to be a promising combination for maximizing both input and maximum power while a 10-minute delay generally results in higher efficiency. However, further analysis and experimentation are needed to fully optimize the system, considering factors such as PV panel surface temperature and coolant properties.

The experimental test results will be presented in the form of images as Figure 4 to 6. These figures show the condition and performance results of the solar panel. The condition and performance of the solar panel are greatly influenced by the intensity of solar radiation that can be captured by the solar panel, as well as the weather and the surrounding conditions at the time of experimental testing. Therefore, these factors greatly influence the increase and decrease in solar panel performance. However, theore-

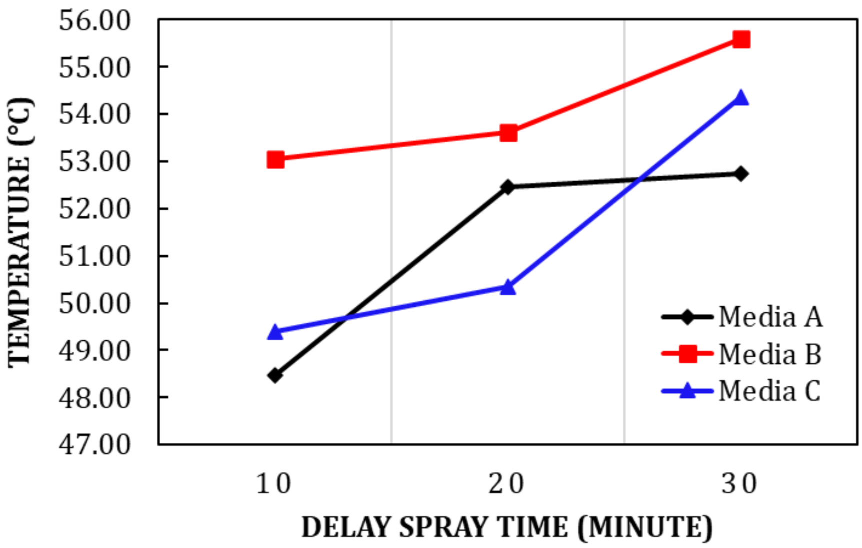

Figure 4. Experimental test results of average temperature

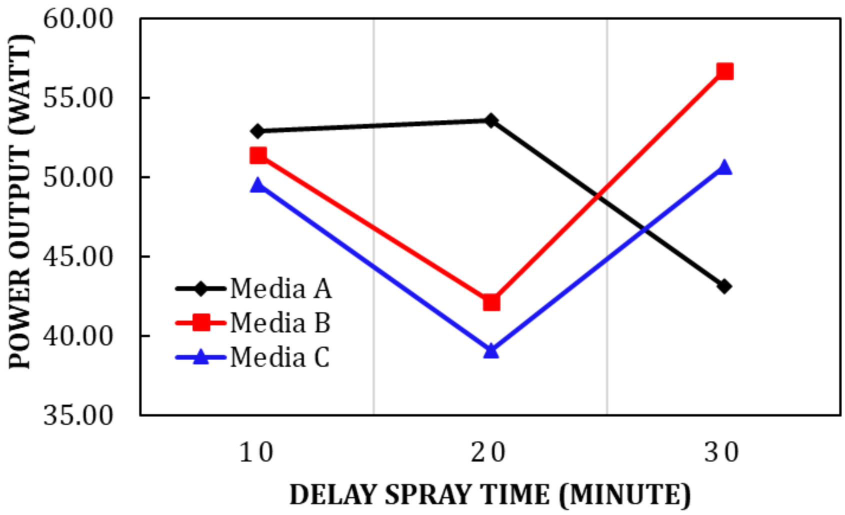

Figure 5. Experimental test results of average power output

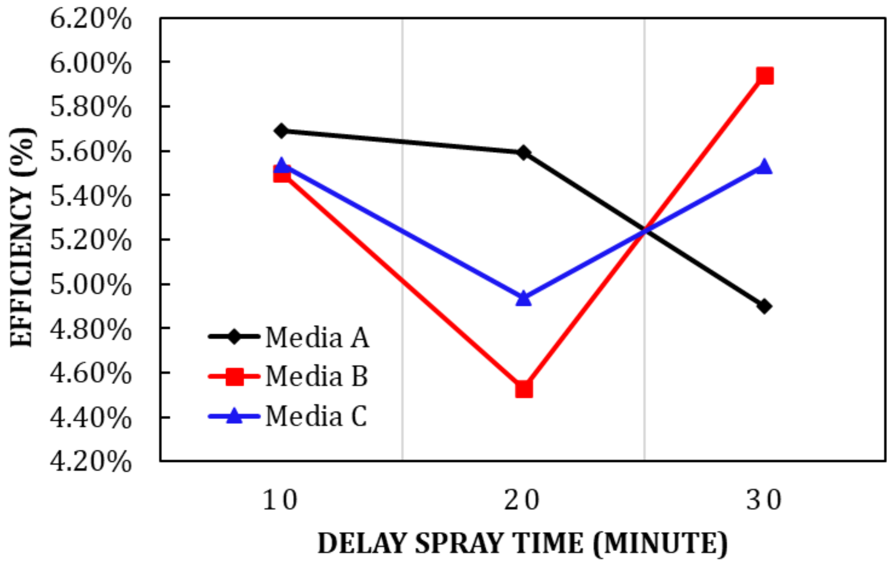

Figure 6. Experimental test results of average efficiency

Table 4. Analysis of Variance on Temperature

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Media Coolant	2	15,525	7,762	5,46	0,072
Delay Time	2	23,306	11,653	8,20	0,038
Error	4	5,684	1,421		
Total	8	44,515			

Table 5. Variance analysis of output power

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Media Coolant	2	4,671	2,335	0,04	0,957
Delay Time	2	54,798	27,399	0,52	0,632
Error	4	212,440	53,110		
Total	8	271,909			

Table 6. Analysis of Variance on Efficiency

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Media Coolant	2	0,000001	0,000000		
Delay Time	2	0,000051	0,000026	0,01	0,986
Error	4	0,000114	0,000029	0,90	0,477
Total	8	0,000166			

tically, it is explained that any increase in the temperature of the solar panel can cause the transfer of electrons to decelerate because the semiconductor material of the solar panel is sensitive to temperature changes [20], which will have an impact on reducing the performance produced by the solar panel. This further underlies the cooling system's addition to maintain and improve the performance of the solar panels.

Data processing was carried out using the ANOVA and post hoc test methods (Tukey-Krammer). Table 4 concludes that the spraying time significantly influences reducing temperature, indicated by a P-value <5% (0.05), namely 0.038, which signifies that at least one of the spraying times has an effect against a decrease in solar panel temperature.

Table 5 concludes that the type of coolant media and the spraying time do not significantly influence increasing output power, indicated by a P-value > 5% (0.05), i.e., 0.957 and 0.632, which signifies that the type of coolant media and the spraying time do not influence the increase in solar panel output power. Table 6 concludes that the type of coolant media and the spraying time do not significantly influence increasing efficiency, indicated by a P-value > 5% (0.05), i.e. 0.986 and 0.477, which indicates that the type of coolant media and the spraying time do not influence increasing the efficiency of solar panels.

Statistic Data Testing

Based on Figure 7, the variance analysis calculation shows that at least one spray time lag influences the decrease in solar panel temperature. Therefore, a post hoc test method was carried out to find out the population mean values with significantly different effects. The following is data from supporting post hoc test calculations using the Tukey-Krammer method.

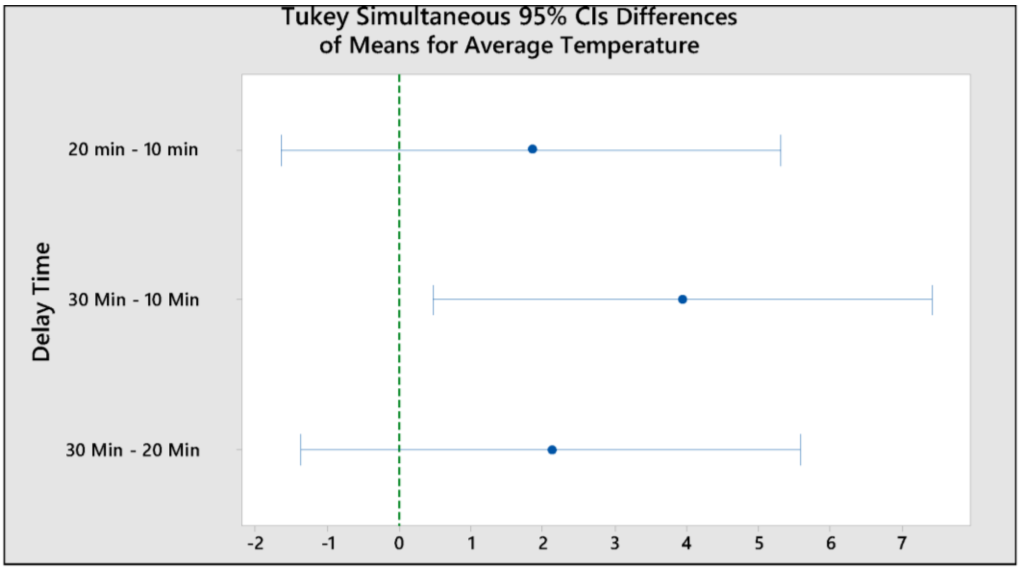

Figure 7. Difference of means

Table 7. Post hoc test of influential variables

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Value
Delay Time	2	23,31	11,653			
Error	6	21,21	3,535	3,30	0,108	3,755
Total	8	44,51				
Critical Range						

Table 8. Difference Value

Difference of Level	Difference of Means	SE of Difference	95% CI	T-Value	Adj P-Value
20 min – 10 min	1,83	1,54	(-2,88;6,54)	1,19	0,499
30 min – 10 min	3,94	1,54	(-,077;8,65)	2,57	0,094
30 min – 20 min	2,11	1,54	(-2,60;6,82)	1,37	0,411

Table 7 shows data processing using the One-way ANOVA method on the spraying time lag variable against temperature drop. It can be seen that the value of the critical range, which is helpful as a reference for the level of significance for testing the influence of variables (spraying time lag on temperature reduction). Table 7 presents the results of testing data on influential variables, with the value of the critical range being 3.755. It can be compared with the difference in the mean value in Table 8 to determine the test level influencing the temperature drop. From this comparison, it can be seen that at the 30-minute - 10-minute level, there is a mean value that passes the critical range value, so it can be concluded that from the 30 minutes - 10 -minutes level, it has a different significance value in lowering the temperature of the solar panel.

On a smaller scale, these techniques can decrease the temperature to 3.94^{o} C with 10-min delayed spray time and media coolant A compared to the 30 min delayed spray time. On the larger scale, we need to calculate the cost of coolant used in the cooling system. It can be done with the Break-Even Point (BEP) analysis. The comparison between the total cost of volume media coolant and the total energy that generated from PV with the cooling techniques. we use a circular system for cooling by using coolant. So that no coolant is wasted, but it needs to be calculated on a large scale, especially in

Table 9. Response to Temperature Drop

Solution	Coolant	Delay Time	Temperature Fit	Compostie Desirability	SE Fit	95% CI
1	A	10 Min	49,30	0,8836	0,889	(46,84;51,77)

Table 10. Response to Increase in Output Power

Solution	Coolant	Delay Time	Power Fit	Compostie Desirability	SE Fit	95% CI
1	A	10 Min	46,847	0,9954	8,94	(8,39;85,30)

Table 11. Response to Efficiency Improvement

Solution	Coolant	Delay Time	Efficiency Fit	Compostie Desirability	SE Fit	95% CI
1	A	10 Min	0,0561	0,7726	0,0039	(0,0451;0,0672)

months of operation, because in this experiment, it was only in daily conditions.

Subsequently, to find out which factor variables (spraying time lag and type of cooling media) are optimal for the response variables (reducing temperature, increasing output power, and increasing efficiency), analysis was carried out using statistical methods to produce the following data (Table 9 to 11). Table 9 produces an optimal response in reducing solar panel temperature, with the lowest value at 49.3°C; Table 10 produces an optimal response in increasing solar panel output power, with the highest value at 46.85 Watts; and Table 11 produces an optimal response in increasing solar panel efficiency, with the highest rating at 5.6%. Then, analysis obtained the result that if the time is 10 minutes and coolant media type A has the optimal performance in increasing output power and efficiency. These three data concluded that as the solar panels' temperature decreases, the solar panels' output power and efficiency will increase.

CONCLUSIONS

Conclusions in this research use data calculations from experimental tests and statistical data analysis. Thus, implementing a solar panel cooling system reduces temperature and increases the performance of solar panels. Application of a spraying time interval of 10 minutes and with type A cooling media can result in a decrease in temperature and an increase in performance that is better than other variables. The ANOVA analysis indicates that the spraying time lag significantly influences the reduction of solar panel temperature (p-value = 0.038). However, the type of coolant media and the spraying time lag do not significantly affect the increase in output power and efficiency (p-values > 0.05 for all cases). The response optimizer analysis indicates that Solution 1 with Coolant A and a 10-minute delay yields the most desirable outcome across all three response variables: temperature drop, increased output power, and improved efficiency. This solution demonstrates a high composite desirability value, suggesting that it is the optimal choice for optimizing the overall performance of the solar panel cooling system.

Future Work

After conducting experimental tests to collect data on a cooling system using spraying media coolant and delayed spraying time, we found that it can reduce the PV panel's surface temperature and maintain both power output and efficiency. In the next project, this cooling technique can be tested on a larger scale, operating monthly with a circular coolant media system. A Break-Even Point (BEP) analysis can then be conducted to compare the total energy generated with and without this cooling system.

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DECLARATION OF CONFLICTING INTERESTS

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