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Experimental Investigation of Photovoltaic Systems Cooling with Binary Mixture Spray

Fotovoltaik Sistemlerin İkili Karışım Sprey ile Soğutulmasının Deneysel İncelenmesi

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ABSTRACT

In this study, it is aimed at achieving more effective and faster cooling by using a binary mixture (water-ethanol) in the spray cooling of photovoltaic systems. The panel cell temperature-efficient working range of photovoltaic systems can be defined as 25-45°C. In this experimental study, when the panel cell temperature exceeded 45°C at 1000 Wm^{-2} radiation, spray cooling was performed until it was reduced to 25°C. In the cooling process, faster cooling was achieved by using 15%, 30% and 45% ethanol in the binary mixture. The DXD-HSI-6 nozzle was used at different liquid and air flow rates in the spray cooling experiment setup, and the ALR (air-liquid ratio) was calculated. In the spray cooling process of the photovoltaic system with a binary mixture, the effect of ethanol on cooling was investigated in all experiments. The fastest cooling was achieved at a liquid flow rate of 800 ml/min and an air flow of 4.5 m^3/h. In the cooling process with pure water, it has been observed that the panel cell temperature can be reduced below 25°C by applying a 100-second spray, and when 45% ethanol is added, the time is reduced to 75 seconds by cooling 25% faster.

Keywords: Spray cooling, atomization, Photovoltaic system, binary mixture, ethanol.

ÖZ

Bu çalışmada, fotovoltaik sistemlerin sprey soğutmasında ikili karışım (su-etanol) kullanılarak daha etkili ve hızlı soğutma sağlanması amaçlanmıştır. Fotovoltaik sistemlerin panel hücre sıcaklığı verimli çalışma aralığı 25-45°C olarak tanımlanabilir. Bu deneysel çalışmada, panel hücre sıcaklığı 1000 Wm^{-2} radyasyonda 45°C'yi aştığında, 25°C'ye düşene kadar sprey soğutma uygulanmıştır. Soğutma sürecinde, ikili karışımda %15, %30 ve %45 etanol kullanılarak daha hızlı soğutma sağlanmıştır. Sprey soğutma deney düzeneğinde farklı sıvı ve hava akış hızlarında DXD-HSI-6 meme kullanılmış ve ALR (hava-sıvı oranı) hesaplanmıştır. İkili karışım ile fotovoltaik sistemin sprey soğutma sürecinde, tüm deneylerde etanolün soğutma üzerindeki etkisi araştırılmıştır. En hızlı soğutma, 800 $mldak^{-1}$ sıvı akış hızı ve 4.5 m^3sa^{-1} hava akışı ile elde edilmiştir. Saf su ile soğutma sürecinde, panel hücre sıcaklığının 100 saniyelik sprey uygulaması ile 25°C'nin altına indirilebileceği ve %45 etanol eklendiğinde, sürenin %25 daha hızlı soğutma ile 75 saniyeye düştüğü gözlemlenmiştir.

Anahtar kelimeler: Püskürtmeli soğutma, atomizasyon, Fotovoltaik sistem, ikili karışım, etanol.

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Introduction

Nowadays, the majority of the energy needed is obtained from fossil fuel sources. It causes water, soil, and air pollution in the environment due to the harmful waste produced as a result of the processing of fossil fuels. In addition, fossil fuels have disadvantages such as being limited and not sufficient to meet the ever-increasing energy need. For this reason, instead of fossil fuels, which cause negativities such as climate change and environmental pollution on a global scale, it has necessitated the use of renewable energy sources, which are of great importance for the future of living things, and cause less destruction in the environment and active use of energy (Anonymous 2018). One of the most important advantages of renewable energy sources is that they help protect the environment by reducing harmful gas emissions. Another important advantage is that they contribute to increasing employment in energy and reducing dependence on foreign countries, as they are domestic resources (Akman, 2019).

Solar energy, one of the renewable energy sources, has the feature of having an endless energy source and is used today in heating workplaces and homes, using hot water and producing electricity (Özgeçmen, 2007). All of the solar radiation absorbed by photovoltaic layers cannot be converted into electrical energy, and some of it is given to the environment as waste heat. Waste heat given to the environment causes the electric current efficiency of the solar layer to decrease, which causes the temperature value of the solar panels to increase (Huang et al., 2001). The output power of photovoltaic cells decreases when the operating temperatures of solar panels increase. For this reason, it is important to maintain the optimal operating temperature of solar cells in order to have better performance (Akman, 2019). Photovoltaic thermal systems (PV/T) (Figure 1), which are among the solar systems, are systems that cool the waste heat generated by solar energy that cannot be converted into electrical energy, remove it from the cell, and convert it into a useful position by keeping the operating temperature of the system at the same level.

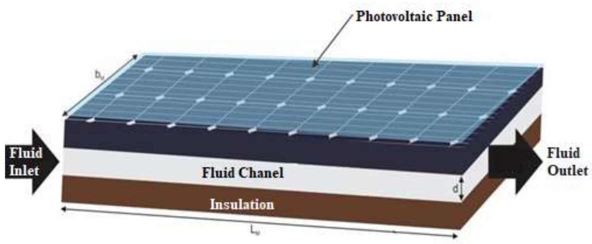

Figure 1.
A General PV/T System Schematic (Diwania, 2020).

In 1976, Martin Wolf first mentioned the combination of the photovoltaic system and the liquid heating thermal method using the Hottel-Whillier analysis method on a flat plate. As a result of this analysis, it has been revealed that PV/T systems are feasible in terms of cost and technique, and that the energy production in the reduced surface area is quite high by minimizing the installation usage area compared to classical thermal methods. Anonymous (2020) Microchips, one of the most advanced technologies with high power, need to remove a large amount of heat from a limited surface. In order to solve such problems, it is of vital importance that the heat fluxes of microchip components in computers be 500 Wcm^{-2} and their hot points be 1000 Wcm^{-2} in the coming years. Such high requirements can be met by direct cooling methods such as spray cooling (Figure 2).

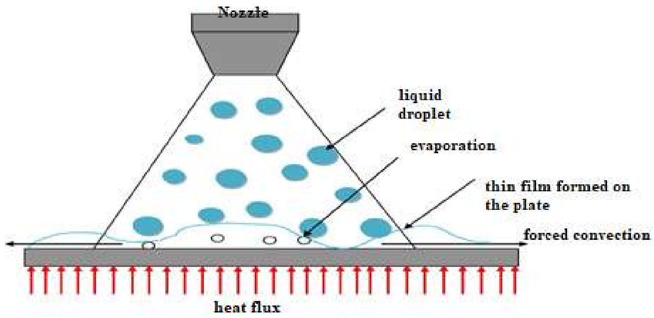

Figure 2.
Spray Cooling (Jafari, 2014).

The physical properties of alcohol make it an ideal additive in the practical application of electronic cooling due to its environmental friendliness and good compatibility with other materials, and it is soluble. No device or nozzle corrosion due to salts or clogging by nanoparticles. It has been shown that adding a small amount of alcohol to water can significantly reduce the surface tension and contact angle. It is an effective way to increase heat dissipation and control surface temperature simultaneously. As the alcohol content increases, the heat transfer capacity enhancement intensity first increases and then weakens slightly. For spray atomization, the Weber number, which is the ratio of inertial forces to surface tension forces, must be high, and adding alcohol to water increases the Weber number (Liu et al., 2019).

$$We = \frac{\varrho_l v^2 D_0}{\sigma} \qquad (1)$$

Spray cooling

It is a cooling mechanism in which phase variation occurs with spray droplets to increase the efficiency of heat transfer. Spray cooling is used in the cooling of hot gases, in the skin area, in the cooling of electronic devices where high temperatures are not preferred, and in fire protection (Figure 3). Spray cooling plays an important role in improving microstructures after steel strip casting and hot rolling with high temperature levels (up to 1800 K) from the operating industry and metal production. Characteristically, it is sprayed into hot areas to cool jet fuel carrying water droplets. The heat transfer mechanism in spray cooling is divided into 4 main groups. The list of them;

-Fixed nucleation surfaces in the heated area

- Convection forced by the impact of droplets,

- Evaporation on the film surface,

- It is secondary nucleation with spray droplet

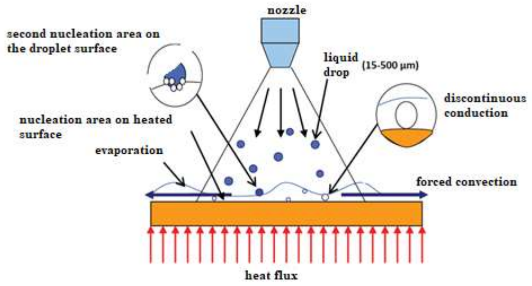

Figure 3.
Mechanism of heat transfer in spray (Yan et al. 2011).

Evaporation from liquid thin film layer
The evaporation of liquid molecules from the liquid layer area is an important heat transfer mechanism for cooling the spray. The schematic view of the formation of a liquid film on the heated area when spray cooling is started is given in Figure 4. This layer is generally 300-500 μm thin.

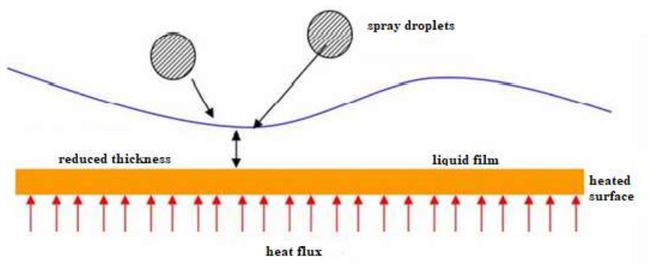

Figure 4.
View of evaporation from the liquid film layer (Yan et al. 2011).

Forced convection as a result of impact of droplets
As a result of the droplets hitting the thin liquid layer, the force generated by the droplets causes enhanced forced convection in the liquid layer (Figure 5). In forced convection, the fluid is forced to flow over a compressor, fan, pump, or similar surface or into the tube, depending on an external factor.

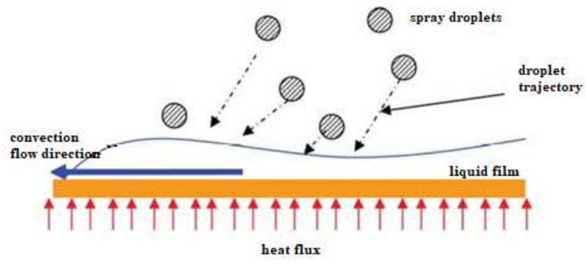

Figure 5.
Appearance of forced convection as a result of impact of droplets (Yan et al. 2011).

Fixed nucleation zones in the heated layer
When the studies on this subject are examined, it has been determined that bubbles grow in fixed nucleation areas on the heated surface. It has been reported that this is caused by growth-promoting activations in the bubbles. The bubbles begin to grow in the core area, absorbing heat from the heated region (Figure 6).

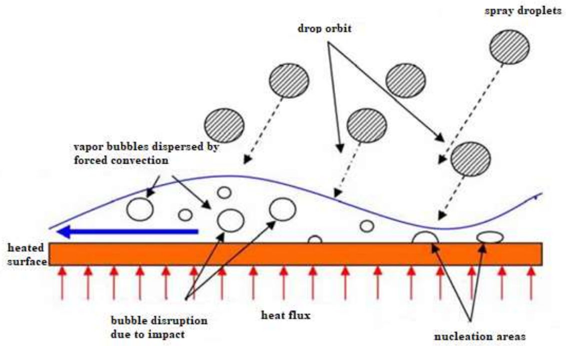

Figure 6.
View of the fixed nucleation zone in the heated area (Yan et al. 2011).

Due to the large number of secondary core regions due to spray droplets, spray cooling is an important mechanism for removing the high heat flux coming from the surface heated by the boiling of the pool. (Yan et al. 2011)

Spray cooling is an effective cooling method for high heat flux applications due to its high heat removal capacity at low coolant flow rates. In spray cooling, coolant droplets produced by the spray nozzle continuously impinge on a hot surface and remove heat through forced convection, thin-film evaporation, or even nuclei boiling. Over the past few decades, a number of studies have focused on the spray nozzle, coolant, spray characteristics, cooling regimes, and surface treatment. It has been studied experimentally using water sprays produced by a full-cone nozzle to cool a sputter-coated thin-film heater on a silicon wafer. For best cooling, the optimum spray height occupies less space than the heater, and the optimum spray height decreases with increasing flow rate. It was found that the increase and decrease of cooling performance is generally consistent with the increase and decrease of spray flow (Gao and Li, 2017).

In this study, where the atomization effects on the heat transfer properties of spray cooling are explained, it has been seen that the heat transfer effect can be improved as the diameter of the nozzle increases. The results of the spray coating width were seen at 20 Lh^{-1} and 30 Lh^{-1} flow rates. It sprayed 30 mm at 20 Lh^{-1} and 40 mm at 30 Lh^{-1}. The angle of the spray cone has significant effects on cooling. As the diameter of the nozzle increases, the exit velocity of the droplet and the angle of the spray spine decrease, and the heat transfer effect can be improved (Bao et al., 2019).

In the study by Nategi et al. (2021) spray cooling was experimentally examined to increase photovoltaic panel efficiency. In this experiment, the effects of spray angle, distance of the nozzles to the PV panel, number of nozzles and vibrating water spray on the PV panel performance were investigated. Spray angles varied from 15° to 50°. It was shown that decreasing the spray angle by 15° increased the electrical efficiency of the PV panel to 19.78% and simultaneously decreased the average PV temperature from 64° to 24°. Additionally, the nozzle–to-PV panel distance was changed from 10 cm to 50 cm, and the best result was achieved for the lowest distance, with an 86% increase in power output. The effects of water spray angle, water flow rate, and nozzles on PV panel distance were evaluated for PV panel performance. Experiments show that water spray cooling improves PV panel performance. The results of this study support the idea that electrical efficiency and output power increase by reducing the spray angle of the cooling water.

Wibowo et al. (2024), This research investigates the cooling effects of different types and sizes of water sprays on photovoltaic (PV) panels to enhance performance by reducing temperature. Conducted between 08:00-15:00, it was found that a full cone nozzle with a 2 mm diameter reduced panel temperature from 61.96°C to 36.51°C and increased efficiency from 10.98% to 14.47%. Full cone nozzles provided better cooling due to more even water distribution compared to hollow cone and flat fan nozzles. Variations in nozzle diameter also impacted cooling effectiveness.

In the study conducted by Kim et al. (2007) a steel plate was heated to 900℃ in a muffle furnace. Coolants were also prepared at room temperature (25°C ± 1°C). The nozzle currently used is a full-cone spray nozzle. In the study, (0, 100, 300, 500, 700) ppm ethanol concentration and then 56 ppm surfactant (tween 20) refrigerant were used (Figure 8). The results show that the contact angle value decreases with increasing ethanol concentrations in water. Various coolers have different cooling capacities, which can be defined in terms of coolant consumption and cooling time. The lower the cooling time spent by a cooler, the lower the consumption and, therefore, the higher the cooling capacity. It has been observed that this can be achieved by decreasing the contact angle of the water droplet with the solid surface and increasing the concentration of surfactant or alcohol in the water droplets to ensure rapid evaporation. Additionally, the improvement of spray cooling with an ethanol-water mixture was observed (Figure 7 a,b). In this study, where the results of the nozzle height were also seen, it was seen that the 40 mm distance was more optimized in the experiments conducted between the (20-100) mm plate and the nozzle and gave better results in this and other studies. The surface tension and contact angle of pure ethanol are very low compared to pure water. Therefore, when ethanol is added to water, the contact angle of the resulting droplet decreases as the ethanol concentration increases (Figure 7) (Table 1).

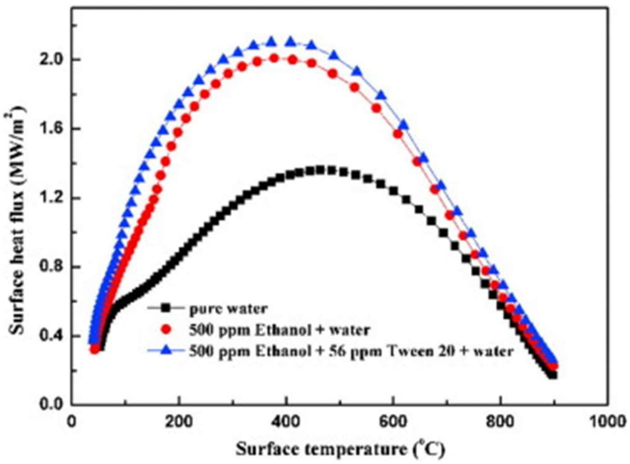

Figure 7.a.

Boiling curve for surfactant (tween 20)-ethanol-water mixture (Bhatt NH et al. 2017).

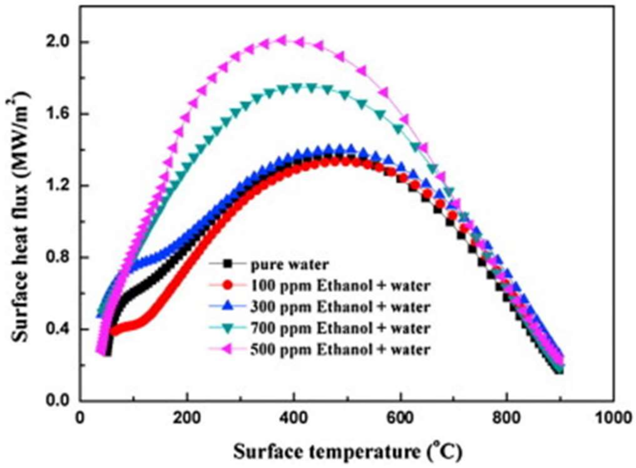

Figure 7.b.

Boiling curve for ethanol-water mixture (Bhatt NH et al. 2017).

Table 1.

A Table of Velocities (Bhatt NH et al. 2017).

Coolant	Cooling Rate (°Cs^{-1})
Pure water	45
Ethanol 100ppm	57
Ethanol 300ppm	61
Ethanol 500ppm	70
Ethanol 700ppm	55

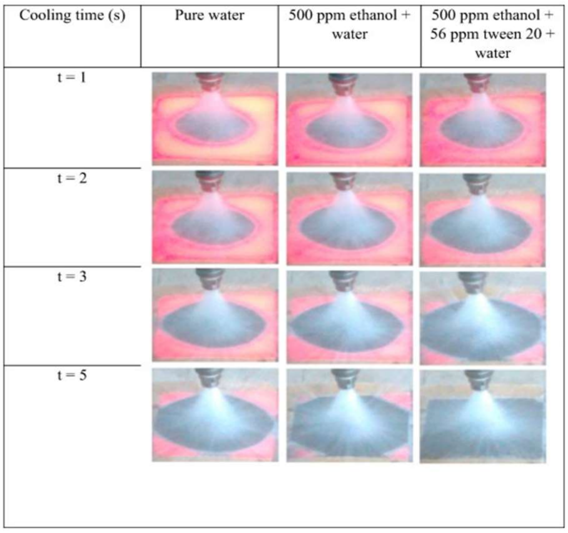

Figure 8.

Water, 500ppm ethanol + water, 500ppm ethanol + 56 ppm tween 20 + water cooling phases in 5 seconds were recorded (Bhatt NH et al. 2017).

An experimental study presents the optimization of the parameters involved in air-assisted water spraying on the PV panel surface. The effect of spray cooling on panel performance was examined and electrical efficiency decreased due to the increase in cell temperature. Effective parameters have been determined to prevent this decline. These parameters were examined at three levels: spraying time, spraying flow rate, nozzle air flow rate, nozzle-to-panel distance, and solar radiation. As a result, the optimum values for the highest electrical efficiency were obtained as 49.9 s for spraying time, 0.0180 m^3hour^{-1} for spraying flow rate, 2 m^3hour^{-1} for air flow rate, 50 cm and 700 Wm^{-2} for the distance from nozzle to panel (Yesildal, F. et al. 2021).

In this experimental study, the system was designed by taking into account other studies in the literature, and by using ethanol + water in different ratios with controlled spray cooling and by trying the DXD-HSI-6 nozzle type to reduce the temperature increase caused by solar radiation coming directly to the cells of the Photovoltaic system. Cooling formation was observed. Additionally, it has been observed that using 15% (15-30-45%) ethanol provides better cooling than water.

Material and Methods

Experimental setup

A nozzle, positioned at a height where the spray can form, and five halogen lamps, each with a power of 500 W, have been placed on the photovoltaic panel. The nozzle, which has air and water inlets, is set to supply pressurized air from an air tank pressurized by a compressor up to a maximum of 8 bars, and water + ethanol and water from a 20-liter water tank pressurized up to a maximum of 4 bars. After making the necessary adjustments, a maximum air flow of 4.5 m^3h^{-1} and a minimum air flow of 3 m^3h^{-1} were provided in the air flow meters. In the water flow meter, a minimum liquid flow of 400 $mlmin^{-1}$ and a maximum liquid flow of 800 $mlmin^{-1}$ were provided. These minimum and maximum values were adjusted according to the atomization of the spray.

The system operates within the temperature range of 25-45°C, and the start and end times of the spray are recorded with the help of a data logger based on these temperatures. The spray cooling starts at 45°C and continues until the temperature drops to 25°C. (Figure 9-10) (Table 3).). Here D_0 represents the diameter of the nozzle and σ_l represents the surface tension. The physical properties of ethanol are given in Table 2.

Table 2.

Physical Properties of Ethanol at 25°C (Xu H. et al. 2021).

Property	Unit	Value
Intensity	kgm^{-3}	789
Surface tension	Nm^{-1}	21.97 × 10-3
Dynamic viscosity	mPa.s	1.074
Electrical conductivity	Sm^{-1}	5 × 10-5
Boiling point	°C	78
Specific heat	$kj(kg°C)^{-1}$	2.58
Heat of vaporization	$kjkg^{-1}$	837.36
Thermal conductivity	$W(mK)^{-1}$	0.171

Figure 9.

General View of the Experimental Setup

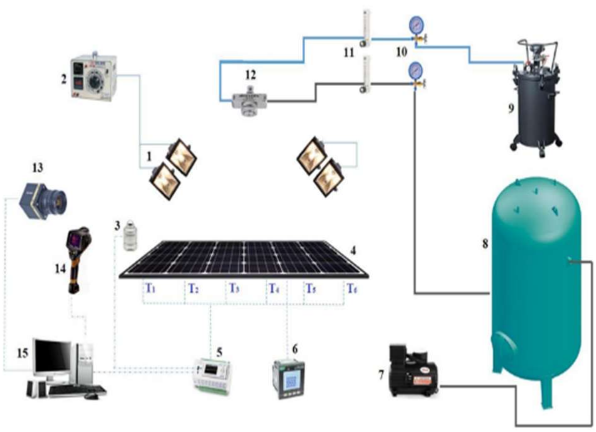

Figure 10.

Experimental system schematic representation

Table 3.

Materials Used in the Experiment System

1	Halogen Projector	9	Water tank
2	Variac	10	Heat and Air Inlet Pressure
3	Pyranometer	11	Water and Air Flowmeter
4	Photovoltaic Panel	12	Nozzle
5	Data Recorder	13	CCD Camera
6	Power Analyzer	14	Theme Camera
7	Compressor	15	Computer
8	Air tank	T 1-6	Thermocouples

DXD-HSI-6 nozzles, which have a single piece spraying feature, are atomized after air-water entry. Nozzles with a full cone spray amount have a maximum coverage area of 35 cm.

Table 4.

DXD-HSI 6 Technical Specifications

MODEL	DXD-HSI-6
Liquid and air inlet	¼'' BSB
Hole diameter at liquid inlet	Ø4 mm
Nozzle hole diameter	Ø1 mm

Results

Experimental data of pure water and ethanol mixtures

The experimental results of 3 m^3h^{-1} and 4.5 m^3h^{-1} air flow rates and 400 $mlmin^{-1}$ and 800 $mlmin^{-1}$ pure water and ethanol mixtures in certain proportions are detailed in the graphs below. are given, and ALR (air-liquid) ratios are calculated.

$$ALR = \frac{m_{air}}{m_{liq}} \quad (2)$$

In the spray cooling experiment performed by adding only water and 15%, 30% and 45% ethanol to water at an air flow rate of 3 m^3h^{-1} and a liquid flow rate of 400 $mlmin^{-1}$, when only water was used, the panel temperature changed from 45°C to 25°C in 120 seconds. It has also been observed that it cools. It was observed that faster cooling compared to water was achieved at rates of 32.52% in the 15% ethanol mixture, 41.8% in the 30% ethanol mixture, and 44.1% in the 45% ethanol mixture (Figure 11).

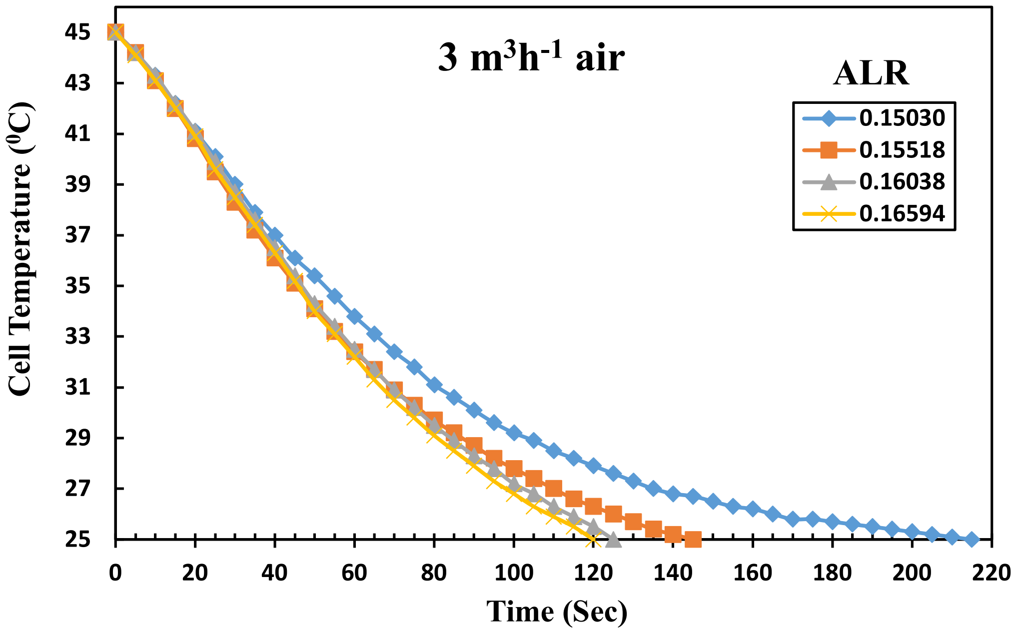

Figure 11.
Time-dependent cooling chart at 3 m^3h^{-1} air and 400 $mlmin^{-1}$ liquid

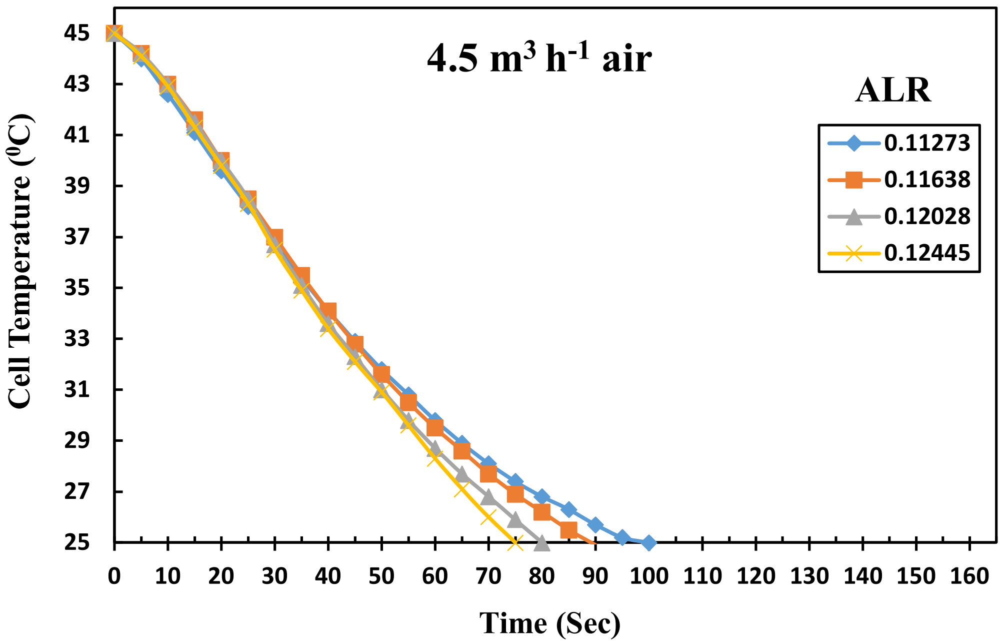

Figure 12.
Time-dependent cooling chart in 4.5 m^3h^{-1} air and 800 $ml.min^{-1}$ liquid

Table 5.

Fluid and ALR Ratios

Fluid	ALR
Water	0.15030
Water + % 15 ethanol	0.15518
Water + % 30 ethanol	0.16038
Water + % 45 ethanol	0.16594

In the spray cooling experiment performed by adding only water and 15%, 30% and 45% ethanol to the water at an air flow rate of 4.5 m^3h^{-1} and a liquid flow rate of 800 $mlmin^{-1}$, the panel temperature increased from 45°C to 25°C by 100°C when only water was used. It has been observed that it cools in seconds. It was observed that when ethanol was added at the specified rates, faster cooling was achieved with a decrease of 10-20-25% respectively (Figure 12).

Table 6.

Fluid and ALR Ratios

FLUID	ALR
Water	0.11273
Water + % 15 ethanol	0.11638
Water + % 30 ethanol	0.12028
Water + % 45 ethanol	0.12445

Uncertainty analysis

In the spray cooling process in the photovoltaic panel system, measurements were made with temperature, flow, and pressure measurement elements. Uncertainty analyses for the measurements were made. Uncertainty analyses provide reliable information about the experimental results obtained. The most important effect of these analyses is to determine the one that causes the highest deviation among the parameters in the experiments (Akpınar, 2005). Deviations that occur in the measurement of test inputs can be grouped as random, fixed, and production-related deviations. The equation given below was used to calculate the total error (Holman, 2012).

$$W_R = \frac{\partial w_r}{\partial x} = \left[\left(\left(\frac{\partial R}{\partial x_1}\right) w_1\right)^2 + \left(\left(\frac{\partial R}{\partial x_2}\right) w_2\right)^2 + \left(\left(\frac{\partial R}{\partial x_3}\right) w_3\right)^2 + \cdots + \left(\left(\frac{\partial R}{\partial x_n}\right) w_n\right)^2\right] \qquad (3)$$

Here, R is the function of the independent variables. The uncertainty of the independent variables is named W1, W2, Wn. WR (x1, x2, . xn) is the amount of uncertainty consisting of different independent variables (Table 16)

Table 7.

Uncertainties Measured in Parameters

Variable	Uncertainty (WR)
Air Flow Rate	0.08
Water Flow Rate	0.055
Heat	0.0143
Nozzle Diameter	0.001
Pressure	0.045
Pyranometer	0.027

Conclusions

In this study, the solar radiation intensity of photovoltaic panel systems cooled by binary mixture spray the decrease in cooling rate compared to water by mixing ethanol in certain proportions were examined. Optimum operating temperature ranges, air-liquid flow rates, and ethanol ratios were determined for the experiments, and the results obtained at the end of the experiments are given below.

In the spray cooling experiment conducted at 1000 Wm^{-2} radiation, it was observed that the effect of ethanol on cooling was positively reflected and the decrease in the cooling rate was directly proportional to the increase in ethanol.

The refrigerant we used in the binary mixture spray cooling experiments is ethanol. Due to the thermodynamic properties of ethanol, whose boiling point temperature is lower than that of water, ethanol mixed in certain proportions has an effect on cooling.

In spray cooling performed with 15%, 30% and 45% ethanol mixtures, it has been observed that as the ratio of ethanol increases, the effect of spray cooling increases compared to water.

According to the calculated ALR ratios, it has been observed that as the ALR ratios increase, the cooling times decrease.

The fastest cooling time for water was found to be 100 seconds in the spray cooling process at 4.5 m^3h^{-1} air and an 800 $mlmin^{-1}$ liquid flow rate.

The longest cooling time for water was 230 seconds in the spray cooling process at 3 m^3h^{-1} air and a 400 $mlmin^{-1}$ liquid flow rate.

It has been observed that cooling performance increases as the ethanol ratio increases. This increase is due to the fact that ethanol provides a more effective heat transfer mechanism due to its lower surface tension and higher evaporation capacity compared to water.

As a result, the binary mixture spray cooling method has been determined to be an effective method for cooling photovoltaic systems. The use of an ethanol-water mixture shortens the cooling time. These findings contribute to more efficient use of renewable energy resources and increased efficiency in energy production.

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K.Y.: Supervision, original draft preparation.
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References

Anonymous, 2018. Yenilenebilir enerjinin dalları ve açıklaması, https://yenilenebilirenerjisistemi.blogspot.com/2018/02/enerjisi-yenilenebilir enerjikaynaklar.html (20.05.2020)

Akman, Ö. (2019). Fotovoltaik Panellerde Sıcaklığın Elektriksel Verime Etkileri ve Termal Güç Eldesi. [Yüksek Lisans Tezi, Karabük Üniversitesi, Fen Bilimleri Enstitüsü, Karabük].

Özgeçmen, A. (2007). Güneş Pilleri Kullanarak Elektrik Üretimi, [Yüksek Lisans Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, 112s, Ankara].

Huang, S., Lin, T., Hung, W., & Sun, F. (2001). Performance Evaluation Of Solar Photovoltaic/Thermal Systems, *Solar Energy*, 70 (5), 443-448.

Diwania, S., Agrawal, S., Siddiqui, A., S. & Singh, S. (2020). Photovoltaic–thermal (PV/T) technology: a comprehensive review on applications and its advancement. *International Journal of Energy and Environmental Engineering*, (11), 33–54.

Anonymous, (2020). Performance of Photovoltaic Thermal Collector (PV/T) with Diffrent Absorbers Design. http://www.wseas.us/elibrary/transactions/ environment/2009/31- 968.pdf.

Jafari, M. (2014). Analysis of heat transfer in spray cooling system using simulations. [MS Thesis, Mechanical, Automotive and Materials Engineering, University of Windsor, Canada].

Liu, H., Cai, C., Jia, M., Gao, J., Yin, H., & Chen, H. (2019). Experimental investigation on spray cooling with low-alcohol additives. *Applied Thermal Engineering*, *146*, 921-930.

Xu, H., Wang, J., Li, B., Yu, K., Tian, J., Wang, D., & Zhang, W. (2021). Effect of spray modes on electrospray cooling heat transfer of ethanol. *Applied Thermal Engineering*, *189*, 116757.

Yan, L., & Kim, I. H. (2011). Effect of dietary grape pomace fermented by Saccharomyces boulardii on the growth performance, nutrient digestibility and meat quality in finishing pigs. *Asian-Australasian Journal of Animal Sciences*, 24(12), 1763-1770.

Gao, X., & Li, R. (2017). Effects of nozzle positioning on single-phase spray cooling. *International Journal of Heat and Mass Transfer*, *115*, 1247-1257.

Bao, J., Wang, Y., Xu, X., Niu, X., Liu, J., & Qiu, L. (2019). Analysis on the influences of atomization characteristics on heat transfer characteristics of spray cooling. *Sustainable Cities and Society*, *51*, 101799.

Nateqi, M., Rajabi Zargarabadi, M., & Rafee, R. (2021). Experimental investigations of spray flow rate and angle in enhancing the performance of PV panels by steady and pulsating water spray system. *SN Applied Sciences*, 3, 1-13.

Santiko Wibowo, Z. A., Rachmanto, R. A., Himawanto, D. A., & Prasetyo, S. D. (2024). Optimization of Photovoltaic Performance Using a Water Spray Cooling System with Different Nozzle Types. *International Journal of Computational Methods and Experimental Measurements* 12(1), 9-19.

Kim, J. (2007). Spray cooling heat transfer: The state of the art. *International Journal of Heat and Fluid Flow*, *28*(4), 753-767.

Bhatt, N. H., Raj, R., Varshney, P., Pati, A. R., Chouhan, D., Kumar, A., ... & Mohapatra, S. S. (2017). Enhancement of heat transfer rate of high mass flux spray cooling by ethanol-water and ethanol-tween20-water solution at very high initial surface temperature. *International Journal of Heat and Mass Transfer*, *110*, 330-347.

Yesildal, F., Ozakin, A. N., & Yakut, K. (2022). Optimization of operational parameters for a photovoltaic panel cooled by spray cooling. *Engineering Science and Technology, an International Journal*, *25*, 100983.

Akpınar, E. (2005). Deneysel çalışmalardaki hata analizinde bir örnek: Kurutma deneylerindeki hata analizi. *Mühendis ve Makina*, 46(540), 41-48.

Holman, J. (2012). Experimental methods for engineers, 5th edition. McGraw-Hill, 739, New York, USA