Journal of Evrimata : Engineering and Physics
Vol. 01, No. 01, June, 2023, p.30 – 36 e-ISSN: 3025-1265

Analysis of The Cooling Spray System for Hot Pool Water With An Electricity Source from Solar Cells: Case Study of Water Cooling

Bambang Irawan[1*], Syamsul Hadi[2], Samsul Hadi[3], Subagiyo[4], Kris Witono[5]

[1,2,3,4,5]State Polytechnic of Malang, Indonesia

bambang.irawan@polinema.ac.id. Syamsul.hadi@polinema.ac.id, samsul.hadi@polinema.ac.id, Kris.witono@polinema.ac.id

Article Information

Manuscript Received 2023-06-22
Manuscript Revised 2023-06-26
Manuscript Accepted 2023-06-26
Manuscript Online 2023-06-30

ABSTRACT

This study discusses the cooling of water with a system of spraying it into the free air. The energy source to drive the pump uses energy from sunlight. This research is to solve a problem in an area where it is difficult to get water so that the water for the cooling process must be cooled so that it can be used for the next process. The second problem is that the electrical energy is very minimal, so you have to use other energy that can be used for the cooling process. The process of cooling the water spray system into the air was chosen to solve this problem. The tools used in this study were a 600 Wp solar cell, a 300 W water pump and a spray pipe. The research was conducted during the dry season in August. The research results show that the temperature of the water in the pool is not homogeneous the deeper the water in the pool the lower the temperature. The higher the pool water temperature, the longer the cooling time will be. The greater the pump discharge, the faster it will take to cool the pool water. Solar energy is able to supply energy to drive pumps with pool water temperatures up to 45 C. This cooling system can be used at night because it is equipped with batteries. The results of this research can be used and developed to create a larger system. This cooling system does not cause any impact on the environment because the energy source is from sunlight which is environmentally friendly.

Keywords: water cooling, spray system, solar energy, pump

1. INTRODUCTION

Mountainous areas generally lack water, and water is usually taken from limited water sources. Remote places, such as in the mountains, far from cities, there are no electricity networks, so alternative energy is needed to produce electricity. Some mountainous areas in Indonesia are a place to grow crops in plantations. One of the jobs of the farmers is to distill clove leaves into clove oil.

The clove leaf distillation process requires fluid for condenser cooling. Water is a good coolant and environmentally friendly. Cooling water is used to absorb heat energy from the steam resulting from the evaporation of clove oil. The cooled clove oil vapor will turn into a liquid consisting of water and clove oil.

The simple technology that is used by farmers and can be used to cool the distillation steam is the water in the water pool. The pipe containing hot steam from the distillation evaporation process is inserted into the pool of water. As a result of the steam cooling process which takes a long time, the water temperature in the pool continues to rise. If the pool water temperature has reached more than 50 C, the cooling and condensation process is not good because the fluid that comes out of the pipe is still in the form of steam. The farmers had no way of lowering the temperature of the pond water to cool it down. The way to do this is with a very simple method, namely a hot pool of water is left alone until the water cools down on its own. The method used by farmers takes up to 60 hours, so the distillation process stops long enough. How to deal with it so that the pool water temperature cools faster.

The cooling process must be made simple and cheap, bearing in mind that farmers do not have the funds to finance the manufacture and operation of the equipment so that the pool water can cool faster. The selected pool water cooling process is to use a direct cooling system, in which water is sprayed into free air.

The operation of the equipment requires energy, where energy for the process of cooling pool water cannot be taken from electrical energy which requires funds considering the financial capabilities of the farmers. The solution is still to use electrical energy but from other energy sources that don't buy.

This cooling problem, then examined the process of cooling the water spray system into the free air. To push and press water into the pipe using a water pump. The pump requires electrical energy, the selected electrical energy uses an energy source from the sun using a solar cell.

There are many types of water coolers with air coolers but not many use them, especially the open type coolers, many types of water coolers with air have been made as in reference books [1].

The use of a spray system to cool water in open air is a simple, simple and energy-efficient technique. The basis of this system comes from the transfer of heat and mass energy which is quite difficult to understand, so it is rarely studied. This method has long been abandoned even though it is simple and requires tools that are not complicated and inexpensive. The weakness of this system requires a rather large and free land.

This cooling method has been widely used thereby reducing the interest for scientific research on cooling water in air [8]. Currently it is widely used for this cooling system but in the form of cooling towers. Due to the environmental issues that must be properly guarded, there has been a renewed interest in this technology, especially in relation to renewable energy sources.

Spraying water in the air has many applications such as: cooling water, increasing humidity, for agriculture, shrimp ponds, fish etc. The energy used for this process usually uses electricity or other non-renewable energy.

Solar water pumps can supply water to locations that are out of reach of the existing electricity grid [10]. Solar water pumps can replace pump systems that use conventional energy [14]. The water supplied by the solar water pump can be used for anything, including for putting water into the sprayer pipe. A solar water pump system is basically a pump system driven by an electric motor, where the electrical energy is provided by one or more solar panels or Photo Voltaic (PV) [15]. A typical solar powered pumping system consists of an array of solar panels that drive an electric motor equipped with a battery. The choice of battery capacity must be in accordance with the size of the solar cell and pump power [3] and [16].

Pump power can be calculated by the general formula and one of [5].

$$P = \rho . g . H . \dot{V} . \eta t \quad (1)$$

Energy requirements for pumps according to the following equation [6]:

$$Ep = P.t \quad (2)$$

Where t is the length of time the pump is running.

The energy produced by hybrid PV/WT in Indonesia by [12], considering that wind energy in Indonesia is very small and unstable, this reference can be used to consider the continuation of the energy produced by solar cells for one year,

The theoretical basis and formula for calculating heat transfer from water to air are partly taken from researchers [2]. The column size is large compared to the pipe diameter, and because there is no water circulation in the pond, the flow in the pond can be assumed to be one-dimensional [9].

The continuity equation can be written according to [8] and [13], assuming that no air follows the water droplets:

$$\dot{m}w = \rho w . A . \alpha . Uw, \quad (3)$$

$$\dot{V}w = A.Uw$$

$$\dot{m}w = \rho w . \dot{V}w . \alpha .$$

If only water is taken from the fluid, the value $\alpha = 1$ so that

$$\dot{m}w = \rho w . \dot{V}w$$

The mass of the air flow can be calculated as follows,

$$\dot{m}a = \rho a . A \, (1-\alpha) \, Ua \quad (4)$$

For steady-state flow, the specific heat rate equation is:

$$qw = \dot{m}w . Cpw . \Delta Tws \quad (5)$$

$$= \rho w . \dot{V}w . Cpw . \Delta Tws$$

$$qa = \dot{m}a . Cpa . \Delta Ta \quad (6)$$

Because the cooling is direct in the air, the heat released by the water into the air is the same as the heat received by the air, so the efficiency is 100%.

$$qws = qa \quad (7)$$

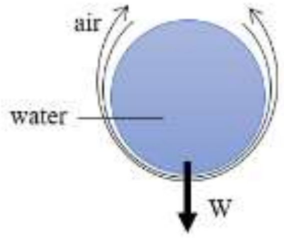

Figure 1 Water droplets as they fall

The size of the water droplets when they rise and fall is actually different, but in this study they are considered the same and all water will come into contact with air. Measuring and calculating the flowing mass of water is easy but difficult to measure the mass of air flow, as well as measuring the temperature of water is easy but difficult to measure air temperature.

The heat transfer that is measured is only the heat released by the water into the air, not the amount of heat energy received by the air.

Equation of the time needed to cool the water in the pool based on heat transfer,

The water energy in the water pool that is wasted into the air is,

$$Ew = mw . Cpw . \Delta Twp \quad (8)$$

$$mw = \rho w . Vp$$

$$Ew = \rho w . Vp . Cpw . \Delta Twp$$

Calculation of heat rate based on energy (7)

$$qw = Ew/t \quad (9)$$

Equation (5) is the same as equation (9)

$$\rho w . \dot{V}w . Cpw . \Delta Tws = (\rho w . Vp . Cpw . \Delta Twp)/t \quad (10)$$

It is assumed that the density of water (ρw) and specific heat capacity (Cpw) are the same between pool water and spray water. So that equation (10) becomes:

$$\dot{V}w . \Delta Tws = Vp . \Delta Twp/t$$

$$t = (Vp . \Delta Twp)/ \dot{V}w . \Delta Tws \quad (11)$$

The cooling time (t) of pool water can be measured or calculated according to equation (11), ΔTwp can be determined from the desired maximum and minimum pool temperatures. The temperature difference ΔTws can be measured based on the water coming out of the sprayer and the temperature of the water when it falls on the surface of the water in the pool.

The distribution of water temperature in a water pool can be measured based on the depth of the water, based on the density of the water that the deeper the density of the water the higher so the temperature is lower.

$$T = c/\rho \quad (12)$$

To calculate the required area of the solar cell or to find out the electrical energy produced by the solar cell, it can be calculated based on the formula from [12]

$$n = Af/Ae \text{ and}$$

$$Et = n \times Ee \quad (13)$$

This equation can be used to calculate the number of solar cells (n) needed or the amount of electrical energy (Et) generated from solar cell energy.

Pump life time (tp) based on the ability of the energy generated by the solar cell can use the following formula,

$$tp = Et/P \tag{14}$$

Water pumps with electric energy from solar cells are widely used in areas that are not covered by electricity or are widely used by farmers who use underground water [4]

2. RESEARCH SIGNIFICANCE

This research needs to be done because no one has yet utilized solar cell energy to be used as a source of energy for cooling hot water in pools.

The results of this research can be directly utilized by the community considering that this research is a case study in dealing with the problem of cooling water for cooling in the distillation process. For science, there is a water cooler powered by solar cells that has never existed before.

This research produces an outdoor hot water cooling system that uses renewable energy and doesn't use a lot of complicated equipment so it's easy to replicate.
The results of this research can be used by all levels of society, from small scale to large scale industries.

The advantage of this cooling system is that energy is not purchased, it is easy to implement, the cooling is direct so that the efficiency of this heat exchanger is high. The drawback is that it requires a larger area for free atmospheric airflow and more water to evaporate into the air when compared to closed cooling.

3. RESEARCH METHODS

3.1 Purpose and Objectives of the Research

This experimental study aims to significantly determine the cooling ability of a water spray system with PV energy. To achieve this goal, the following objectives have been set:

1) Effect of pool water depth on water temperature,
2) The effect of water temperature on the cooling time of the water pool,
3) Effect of water discharge on pool cooling time,
4) The ability of solar energy for the cooling process.

3.2 Materials and tools used in the research

1) Solar cell 600 WP
2) Energy storage battery 170 AH, 12 volt
3) Inverter 1000 W
4) Pump with 300 W electrical input power and pump power, 125 W, 220 volts/50 Hz, total head = 40 m, water discharge 18 liters/minute.
5) Sprayer 12 holes
6) Thermometer
7) Thermoelectric control
8) Hygrometer.
9) The water pool for cooling measures Length x width x height is 6 m x 4 m x 1.5 m. The cooled pipe is 2 inches in diameter, mounted around the inner wall of the pool. The pipe is installed 25 cm from the bottom of the pool and the distance between the pipe and the pipe is 25 cm above. The top pipe is installed 25 cm below the water level.

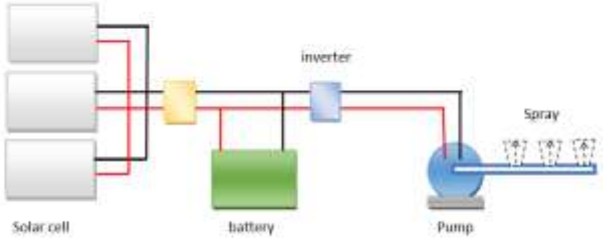

Figure 2 Circuit of the spray system cooling device

Figure 2 shows the arrangement of the tools used for research. The electrical energy generated by the solar cells is supplied to the voltage regulator, with a stable voltage flowing to the battery or directly to the inverter. The flow of electrical energy from the inverter enters the pump so that it works to flow water from the water reservoir to the pipe. The sprayer in the pipe will release water into the free air. If the electrical energy from the solar cell drops because the intensity of sunlight is reduced or blocked, then the electricity supply is directly carried out by the battery. The battery in this series of tools functions to store electrical energy and supply electricity.

Figure 3 Solar cell

Figure 3 shows a solar cell tool that functions to generate electricity from sunlight. Electrical energy from solar cells cannot be used directly because the voltage is unstable, so it needs to be stabilized with a voltage stabilizer.

Figure 4 Battery, inverter and voltage stabilizer

Figure 4 shows several tools such as an electric voltage stabilizer in order to stabilize the electric voltage from the solar cell to the battery or to the inverter. The battery functions to store energy when the electrical energy from the solar cell is not used and as a supplier of energy when the solar cell cannot produce electrical energy. The inverter functions to change electricity from DC to AC and from a voltage of 12 Volts to 220 volts because the pump uses an electric voltage of 220 volts.

Figure 5 Pump and its accessories

Figure 5 shows the pump with its accessories, pipes and sprayers. The pump functions to drain water from the water pool to the pipe with high pressure. The pipe functions to collect water from the pump and the pipe where the sprayer is located. The sprayer functions to spray water from the pipe into the free air.

3.3 Method

Several solar cells are connected in parallel so that the resulting voltage is not large. The solar cell is mounted in a position where sunlight provides maximum energy and this direction does not change.

The energy produced by solar cells in the form of electrical energy enters the voltage regulator and is channeled to the battery and/or inverter which then goes to an automatic device to turn on the pump and then goes to the pump.

The pump works automatically according to orders from the thermocontroller. When the hot water temperature is read by the sensor and the temperature is as expected, the tool will automatically supply electricity to the pump. Hot water from the pool is sucked in by the pump and then flowed into the pipe and from the pipe the water will spurt out through the sprayer. The atomizer will spray hot water into the air, so that the water will be in direct contact with the air resulting in the transfer of heat energy from the water to the air. Thus the water temperature will decrease and the air temperature will rise.

The working time of the pump depends on the hot and cold temperature settings on the thermocontrole. The temperature range of the thermocontroller is set at 50°C to 50°C. Time is recorded from the time the pump starts to run until the pump stops. If the pump is off, it means that the pool water temperature has cooled as specified.

To measure the energy of the water absorbed by the air is to measure the temperature of the water that comes out of the sprayer and that falls into the pool. The water temperature in the pool is measured based on the depth of the pool. This study did not take into account the height of the water jet, the distribution of water and the size of the water droplets produced by the sprayer.

The independent variables of this study are: water discharge, and the amount of solar cell energy.

Dependent variable: the difference in water temperature resulting from the sprayer spray and the length of time it takes to cool the pool water,

The control variable is the water temperature in the water pool.

4. RESULTS AND DISCUSSION

4.1 Results of the research:

The experimental data results show that the cooling time of the water on the surface of the water pool varies, depending on the initial surface temperature. Cooling time is the time to cool surface pool water to 45°C.

The average water temperature on the surface of the pool starts from 50 C to 60 C, the distribution of water temperature on the surface to the bottom of the pool is shown in Figure 6.

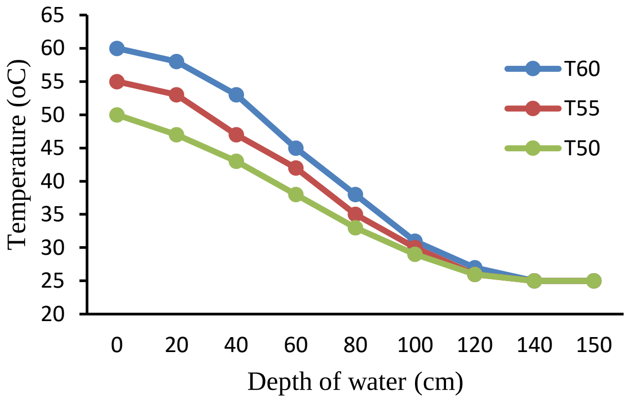

Figure 6 Water temperature in the pool

The deeper of the pool water, the lower the water temperature. Figure 6 shows that the water temperature on the surface is smaller, so the temperature of the deeper water is also lower. Except at a depth of 120 cm to 150 cm the water temperature is relatively the same, namely 25ºC. The water temperature above a depth of 120 cm begins to rise, the magnitude of this increase is not linear.

Figure 7 shows the effect of the sprayed water discharge on the temperature difference between the hot water that comes out of the sprayer and the temperature of the water that falls to the surface of the pool water.

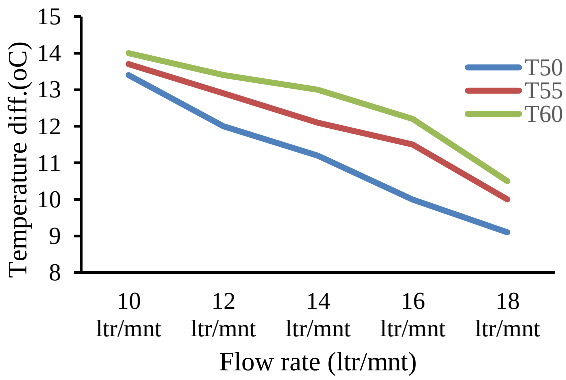

Figure 7 The effect of water discharge on the temperature difference.

The water discharge that is sprayed into the air by the sprayer affects the cooling results of the sprayed water. The temperature difference in question is the temperature of the water when it comes out of the sprayer hole and the temperature of the water when it falls into the pond. The greater the water discharge, the lower the temperature difference. Figure 7 shows that the surface temperature of the water in the pond, the greater the temperature, the greater the temperature difference between the water leaving the sprayer and when it falls to the surface of the water.

Figure 8 shows the effect of surface water temperature and discharge on the temperature difference of the sprayed water.

Figure 4 The effect of temperature on the difference in the temperature of the water

Figure 4 The effect of temperature on the difference in the temperature of the water

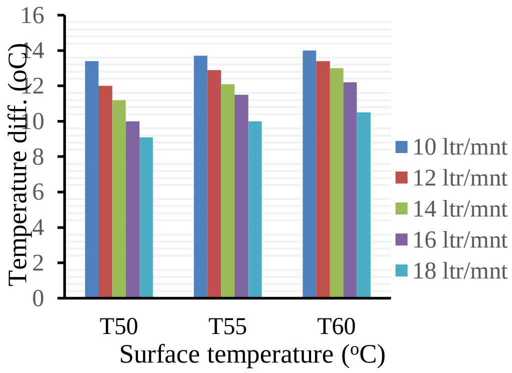

Figure 8 The effect of temperature on the difference in the temperature of the water

Water discharge affects the difference in the temperature of the cooled water, it can be seen in Figure 8 that even though the water surface temperature is different, the discharge still has an effect. The greater the discharge, the lower the cooling temperature difference.

Figure 9 shows the energy yield from hot water that is discharged into the outside air. The greater the temperature of the hot water, the greater the energy released into the air.

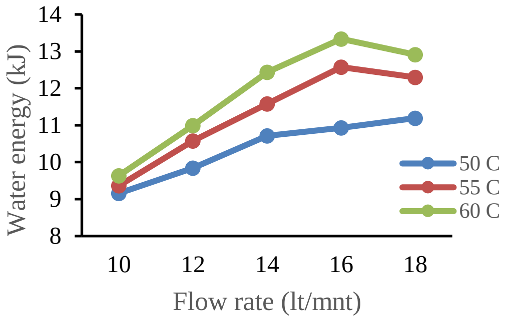

Figure 9 Effect of water discharge on the energy of cooled water

The water discharge affects the heat energy that can be discharged into the free air. The greater the water flow, the more energy can be released, or the more water can be cooled. This is the opposite of the temperature difference, the greater the discharge the smaller the temperature difference.

Figure 10 shows the difference in energy that can be released based on the temperature of the surface water and the flow rate of the water being pumped.

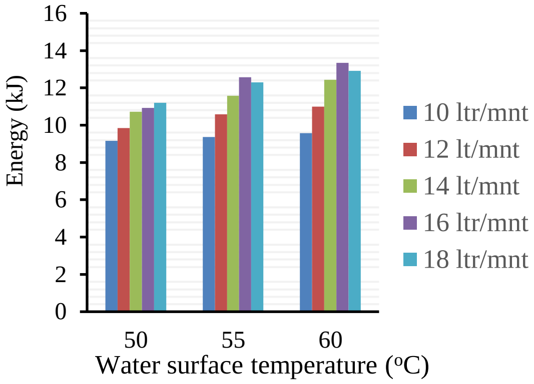

Figure 10. The effect of surface water temperature on the energy released

The temperature of the water on the surface of the pool is different, so the heat energy that can be released is also different. At the same water temperature and different discharge will produce different energy. The greater the discharge, the greater the wasted energy.

The time needed to cool the water in the pond is shown in Figure 11.

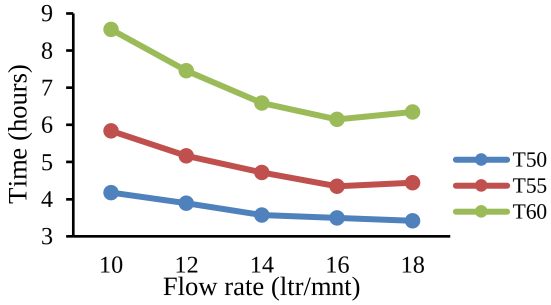

Figure 11 Effect of discharge on cooling time

The higher the temperature of the water at the surface of the pool, the longer it will take for the water to cool. The higher the surface temperature, the greater the thickness of the hot water, as shown in Figure 6. Figure 11 is based on calculation results where data is taken from previous data. The experimental results have a difference of about 15 minutes to 30 minutes.

Pool water cooling is not done until the water temperature reaches ambient air temperature but cooling only to 45°C.

The results of the study of daily solar energy produced by solar cells in August can be seen in Figure 12. It can be seen that the energy produced is relatively almost the same every day.

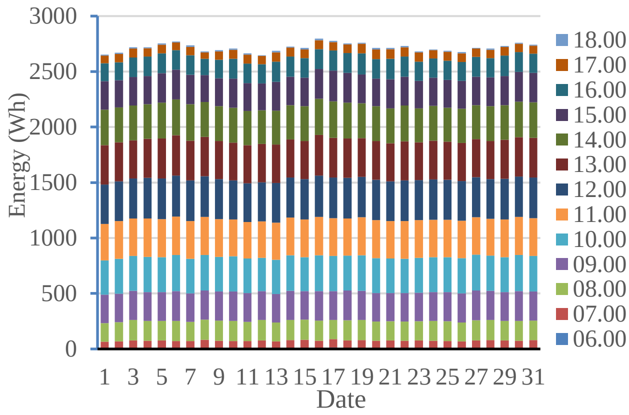

Figure 12 Daily energy produced by solar cells in August

With almost the same daily energy, the energy to drive the pump is getting better and there will be no shortage of energy. The amount of energy produced is between 2,646 Wh to 2,796 Wh. The greatest daily energy is obtained during the day around 11 to 12 noon.

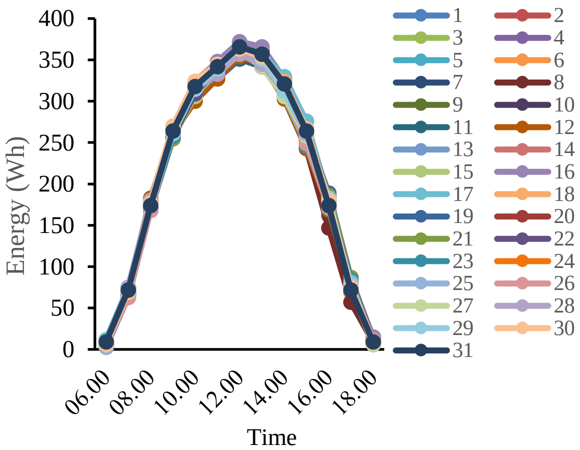

Figure 13 Daily energy generated by solar cells in August from morning to evening

August there is no rain so the energy every day is almost the same. Need attention in the morning and evening the energy drops drastically. To overcome this, a battery is needed to store energy. Equipped with a battery, this tool can work day and night as long as the energy in the battery is still there.

4.2 Discussion of results

1. Water temperature

The deeper the water in the pool, the lower the temperature, this is due to convective heat transfer between the surface of the pipe and the water. As the water temperature rises, the density decreases so that the hot water will rise and the bottom will remain cold.

There are five heat pipes in the cooling pool which are placed from top to bottom. The hot steam enters the upper pipe and then moves in a circle until it exits the pool. Thus, the lower the pipe temperature, the lower the water temperature. The water temperature below is not touched by the pipe so it remains cold.

2. Effect of flow rate and water temperature on temperature differences.

The greater the water discharge, the smaller the temperature difference of the cooling results. Because based on a greater amount of mass, it will release the same heat so that the temperature difference will be smaller, considering that the outside air temperature is constant and the amount of air is fixed.

The higher the surface temperature of the water, the greater the temperature difference of the cooled water. This is because the air temperature remains the same as the water temperature is lower, resulting in more heat absorption.

3. Energy water

The heat energy of water that can be discharged into the air is greater if the discharge is greater. This is because the total mass is greater, although the cooling temperature difference is smaller. It also happens that at higher surface water temperatures, the energy released into the air is greater because of the greater temperature difference.

4. Cooling time.

The cooling time required for higher water temperatures will be longer because the temperature difference is greater and the amount of water cooled is also greater. The amount of water is more because the water temperature in the inside of the pool which has temperatures ranging from 45^0 C to 60^0 C is thicker. Please note that this cooling is only up to 45^0 C.

5. Solar energy

Solar cells are used to convert sunlight energy into electrical energy, the size of the solar cell is 600 Wp. The research was taken in August which is the dry season with no rain at all so it needs attention. The cooling water pool if it rains can work continuously because there is a supply of rainwater from the house which is put into the pool. The energy produced by solar cells is shown in Figures 12 and 13. Every day the energy generated is almost the same because there is no rain. The power generated is quite large, which is between 2,646 Wh to 2,796 Wh.

Is this energy enough to cool the pool of water. This energy is not used directly by the cooler but to drive the pump. Pump power includes an efficiency of 300 Watt, the lowest solar energy is taken, namely 2,646 Wh. Installed 170 AH 12 volt battery or 2040 Wh energy. When direct solar energy is used, the pump can run for about 7 hours. If the pump works at night without sunlight, it can use the energy stored by the battery. The battery provided is capable enough to turn on the pump for 6 hours and for safe use only 5 hours.

With calculations like this and combined with Figure 11, it is expected that the pool surface water temperature should not exceed 55 C. It is safer for hot water to be a maximum of 50 C and has been cooled so that the battery does not work hard. In addition, the maximum used pump discharge is 18 liters/minute.

5. CONCLUSIONS

1. The highest pool water temperature is at the surface. The deeper the water temperature the lower, even at the bottom of the pool remains cold.
2. The higher the pool water temperature, the longer the cooling time will be.

3. The greater the water discharge, the faster the cooling time.
4. Solar energy is able to cool the water in the water pool but is limited to water temperatures up to 45^0 C.

6. ACKNOWLEDGEMENTS

Thanks from the author to individuals or groups who have contributed or supported the research or writing of the article and Thank you to the State Polytechnic of Malang for support of this research

7. AUTHOR CONTRIBUTIONS

- Conceptualization: Bambang Irawan
- Data curation: Syamsul Hadi
- Formal analysis: Samsul Hadi
- Funding acquisition: Subagiyo
- Investigation: Kris Witono
- Methodology: Bambang Irawan and Syamsul Hadi.
- Resources: Kris Witono
- Software: Syamsul Hadi
- Supervision: Subagiyo

8. REFERENCES

[1] John C. Hensley, 2009, Cooling Tower Fundamentals, Published by SPX Cooling Technologies, Inc. Overland Park, Kansas USE, 2009.

[2] Hameed B. Mahood, Adel O. Sharif, Seyed Ali Hosseini, Rex B. Thorpe, Analytical Modelling of a Spray Column Three-Phase Direct Contact Heat Exchanger, Hindawi Publishing Corporation ISRN Chemical Engineering Volume 2013, Article ID 457805, 9 pages http://dx.doi.org/10.1155/2013/457805.

[3] Bambang Irawan, Samsul Hadi, Fatkhur Rohman, Mahros Darsin, 2018, Pemilihan Kapasitas Baterei Penyimpan Energi, Jurnal ROTOR, Vol 11, Nomor 2 Januari 2018.

[4] Kongphope Cha-ar-mart1, Kittiwath Jeebkaew, Archsuek Mameeku, Kunchit Singsoog, Tosawat Seetawan, Solar Cell Water Pump Mobile for Agriculture in Thailand, Journal of Physics: Conference Series 2013 (2021) 012019 IOP Publishing doi:10.1088/1742-6596/2013/1/012019.

[5] Rizgar Baker Weli, Ramzi Raphael Ibraheem, Kawa A. Abdulla, 13, Water Pumping Using Solar Energy, Journal of Science and Engineering Vol. 3 (1), 2013, 35-43.

[6] P Rejekiningrum and Y Apriyana, Design and implementation of solar pump irrigation systems for the optimization of irrigation and increase of productivity, IOP Conference Series: Earth and Environmental Science 622 (2021) 012046 IOP Publishing doi:10.1088/1755-1315/622/1/012046.

[7] S.B. Plass, H. R. Jacobs, and R. F. Boehm, Operational characteristics of spray column type direct contact preheater, AIChE Symposium Series—Heat Transfer, vol. 75, no. 189, pp. 227–234, 1979.

[8] Coban T. and R. Boehm, "Performance of a three-phase, spray-column, direct-contact heat exchanger," Journal of Heat Transfer, vol. 111, no. 1, pp. 166–172, 1989.

[9] H. R. Jacobs and M. Golafshani, "Heuristic evaluation of the governing mode of heat transfer in a liquid-liquid spray column," Journal of Heat Transfer, vol. 111, no. 3, pp. 773–779, 1989.

[10] Ibrahim Alkhubaizi, Solar Water Pump, Int. Journal of Engineering Research and Application www.ijera.com, ISSN : 2248-9622, Vol. 7, Issue 5, (Part -3) May 2017, pp.01-05.

[11] Elias M. Salilih, Yilma T. Birhane, Sofiya H. Arshi, Performance analysis of DC type variable speed solar pumping system under various pumping heads, Solar Energy 208 (2020) 1039– 1047, https://doi.org/10.1016/j.solener.2020.08.071.

[12] Irawan, B., Wirawan, W., Ikawanty, B. A., Takwim, A. (2022). Analysis of the season effect on energy generated from hybrid PV/WT in Malang Indonesia. Eastern-European Journal of Enterprise Technologies, 5 (8 (119)), 70–78. doi: https://doi.org/10.15587/1729-4061.2022.266082

[13] Frank Kreith, Raj M. Manglik, Mark S. Bohn, 2011, Principles of Heat Transfer, Seventh Edition, Publisher, Global Engineering: Christopher M. Shortt

[14] Ali H. A. Al-Waeli, Moanis M K El-Din, Atma H. K. Al-Kabi, Asma Al-Mamari, Hussein A Kazem, and Miqdam T Chaichan, 2017, Optimum Design and Evaluation of Solar Water Pumping System for Rural Areas, International Journal Of Renewable Energy Research, Vol.7, No.1, 2017.

[15] Balkeshwar Singh1 and Anil Kumar Mishra, 2015, Utilization of Solar Energy for Driving a Water Pumping System, International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056 Volume: 02 Issue: 03 | June-2015.

[16] Asian Development Bank, 2018, Handbook on Battery Energy Storage System, DOI: http://dx.doi.org/10.22617/TCS189791-2.