Effect of air inlet velocity on air water harvester with small tube evaporator

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Research Article

Global Journal of Engineering and Technology Advances, 2025, 23(03), 200-208.

Article DOI: 10.30574/gjeta.2025.23.3.0195

DOI url: https://doi.org/10.30574/gjeta.2025.23.3.0195

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Publication history: Received on 28 March 2025; revised on 11June 2025; accepted on 13June 2025

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Keywords: Air-water harvester;Inlet air velocity; Water mass; Heat transfer rate; COP

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Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

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Abstract

During the dry season, parts of Indonesia experience drought and clean water crises. One of the efforts to obtain clean water was by presenting a machine called air-water harvester. The amount of water mass produced depended on several variables such as RH, intake air temperature, type of condensing unit, intake air velocity and engine power. This study aims to determine the performance of the air-water harvester at various inlet air velocities. The dependent variables expected were the mass of water produced, COP, and the amount of heat absorbed from the air. This research was carried out experimentally with the working fluid refrigerant R134a. The compressor used was a rotary type 1 PK compressor. This study varied the air velocity entering the evaporator, namely 1.5 m/s, 3 m/s and 4.5 m/s. The results showed that the highest mass of water was 0.728 kg. Meanwhile, the highest COP was 5.13, and the total heat transfer rate absorbed by the evaporator was 160.38 W. All were obtained at the air velocity of 4.5 m/s.

Keywords: Air-water harvester;Inlet air velocity; Water mass; Heat transfer rate; COP

1. Introduction

Water is a very important compound for all living things, be it humans, animals and plants. However, due to global warming and the dry season, several regions in Indonesia are experiencing drought and people are having difficulty getting clean water supplies to meet their needs. Regarding the drought problem, one solution is to utilize alternative water sources other than water sources from the ground.

One way to obtain clean water is by using the method of capturing water from the air. According to Damanik [1], there are currently several methods of capturing water from the air, including: a) Windmills that capture water from the air. It has several disadvantages, namely it is very dependent on height, installation location, and wind direction, weather, and the installation costs are quite expensive. b) Water catching nets from fog. This method has the disadvantage that the installation location must be in a foggy place and the water obtained is relatively small. c) Water producing machines from the air use vapor compression cycle components. This method has the advantage of using tools and components that are easy to obtain, can be operated indoors or outdoors and the amount of water produced is greater.

Referring to the paragraph above, the third method is the easiest and most suitable method for use on a household scale with power that can still be supplied. This machine is often called an air-water harvester or air-water harvester using a cooling machine. However, this cooling machine needs to be modified in the evaporator section so that it can be used specifically to condense water vapor. Research on air-water harvester machines has been conducted by several previous researchers such as Atmoko[2], Dirgantara[3], Faroni[4], Mirmanto et al. [5], Mirmanto et al. [6] and Mirmanto et al. [7].

Atmoko[2] conducted a study entitled Characteristics of a water-producing machine from air using a vapor compression cycle machine with the addition of an air-compacting fan with a fan velocity of 300 rpm or an air flow velocity of 2.80

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m/s and 350 rpm or an air flow velocity of 3.63 m/s. The results of the study showed that the largest amount of water was found at a fan velocity of 350 rpm, which was 4.2915 liters/hour. However, Atmoko[2] did not mention the velocity of the air entering the machine used. Dirgantara[3] also conducted a study on the effect of the evaporator position on the amount of dew produced using a 0.5 PK air conditioner cooling system and R-134a refrigerant. The evaporator positions that were varied were vertical, 450, and horizontal. The results of the study showed that the largest amount of water was produced by the evaporator in the vertical position, which was 0.3537 kg/7 hours. The Dirgantara[3] research system uses a natural convection system, so the air velocity is not mentioned. Faroni [4] also conducted a study on the effect of the diameter of the condensing unit pipe on the mass of water produced from the air-water harvester. Faroni [4] varied the diameter of the evaporator pipe, namely 3.00 mm, 4.00 mm and 6.35 mm. The results of the study showed that the highest mass of water obtained was 0.369 kg/7 hours using a variation of the pipe diameter of 3.00 mm and Faroni [4] concluded that the smaller the diameter of the pipe used, the more mass of water produced. Meanwhile, Mirmanto et al. [5] studied the effect of the number of evaporators on the mass of water produced, and concluded that the more evaporators, the greater the mass of water produced. Mirmanto et al. [6] studied the effect of air velocity on the mass of water produced and concluded that the greater the velocity, the greater the mass of water produced. Mirmanto et al. [7] studied the effect of temperature on the mass of water produced and they concluded that the higher the inlet air temperature, the less water mass was produced.

The amount of water produced by a water harvester machine depends on various factors such as temperature, RH, evaporator construction, air velocity, free or forced mode, evaporator position, and so on. Meanwhile, according to Dirgantara[3] the vertical position is the best position and according to Faroni [4] the smaller the pipe used produces more water, so this study will use small pipes with a pipe diameter of 1.7 mm and with a vertical position.

By using small pipes and vertical positions, it is expected that the research will produce more water mass. This small pipe evaporator with a diameter of 1.7 mm is already in the lab and has been previously studied by Pengestu[8]. Referring to the research of Dirgantara[3], Faroni[4], Mirmanto et al. [7] and Pangestu[8], this research was focus on assessing the effect of air velocity on engine performance, with: (i) variations in air velocity, namely 1.5 m/s, 3 m/s and 4.5 m/s, because the maximum capacity of the fan to flow incoming air is only 4.5 m/s, while in Mirmanto et al. [7], it is able to produce air velocities of up to 5 m/s, (ii) vertical evaporator position, and (iii) the smallest evaporator diameter is 1.7 mm.

2. Material and methods

2.1. Experimental facilities

The experimental apparatus is shown in Figure 1. It consists of a compressor, a condenser, an evaporator, a bucket, a blower, a fan, and a capillary tube. All temperatures were connected using type K thermocouples and recorded hourly using a data logger Applent AT4524. The air velocities were varied: 1.5 m/s, 3 m/s and 4.5 m/s. They were measured using a digital anemometer GM8092. The mass of water was measured using a digital scale WH-B30 with a resolution of 1 gram.

The air was pushed by the fan to the evaporator box. Inside the evaporator box, the air was cooled by the cool evaporator walls. Hence, the air got low temperatures even lower than the dew point, consequently the part of water vapour in the air condensed and dropped into the bucket. This event occurred continuously, so that the dropped dew accumulated in the bucket. Meanwhile, the dry air and uncondensed water vapour went down and out from the evaporator box. The air velocity was adjusted using a dimmer. The dimmer could regulate the speed of the fan rotation. Increasing the fan rotation elevated the air velocity.

The dimension of the evaporator is given in Figure 2. It consists of top view, front view, side view and three dimensional views. The dimension of the small pipes used was 1.7 mm, while the bigger pipe dimension was ½ inch. To analyze the experimental data, some equations should be used. All equation written and used in this manuscript can be found in Mirmanto et al. [9].

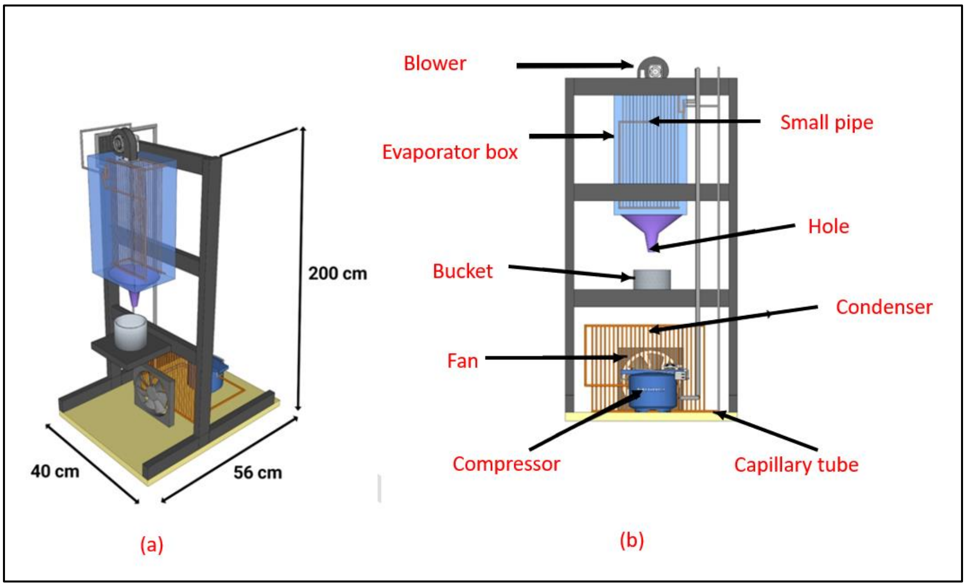

Figure 1 The experimental apparatus (a) three dimensional view, (b) component names

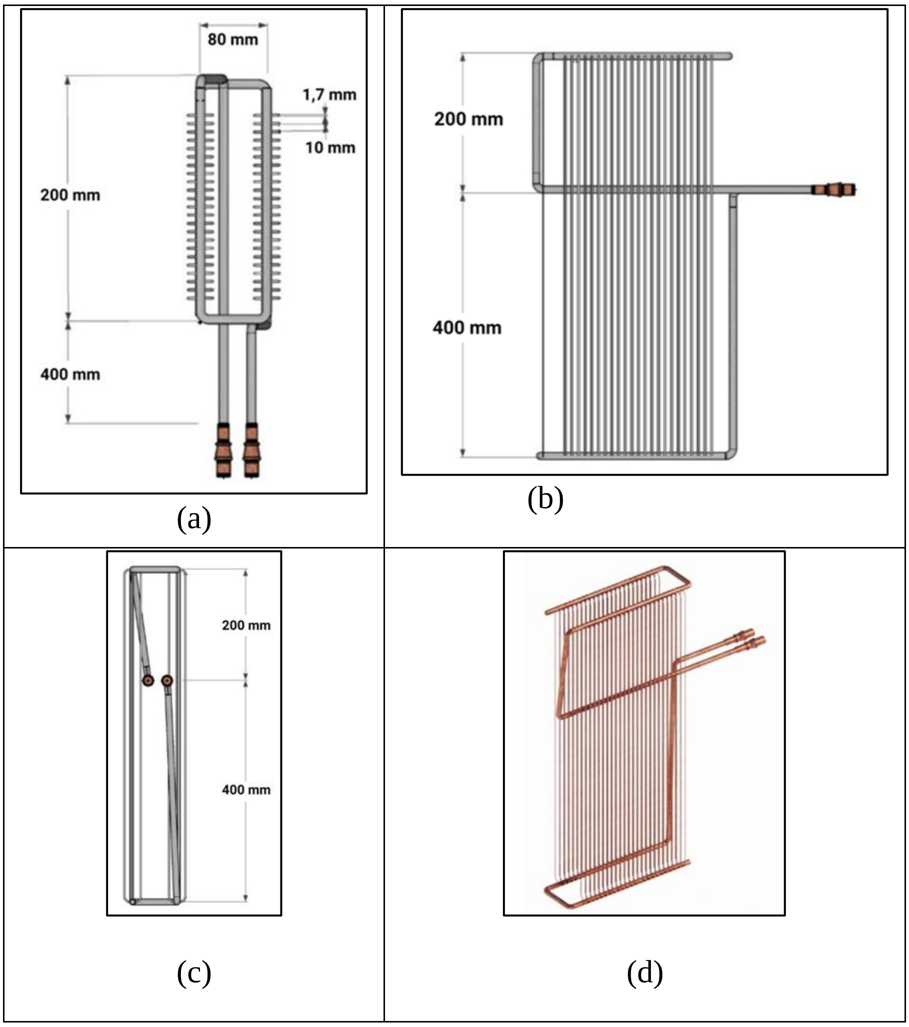

Figure 2 The dimension and the shape of the evaporator. (a) top view, (b) front view, (c) side view and (d) three dimensional view

2.2. Data reduction

Some equations used here were taken from Mirmanto et al. [9]. The electrical power required by the compressor was not only for the vapor compression process, but also to overcome mechanical constraints, friction, vapor leaks, cooling processes, and others. These constraints reduced the compressor shaft power. The power used by the compressor was measured directly using a digital power meter. However, Cengel and Boles [10] wrote that the amount of compressor work per unit mass of refrigerant can be calculated using the equation:

$$W_{in} = h_2 - h_1 \ldots\ldots \quad (1)$$

W_{in} is the compressor work (J/kg), h_1 and h_2 are the enthalpy of the refrigerant at the inlet and outlet of compressor (J/kg). In condenser, refrigerant releases the heat to the ambient through the condenser walls. Then the heat released by the condenser can be calculated as:

$$Q_{out} = h_2 - h_3 \ldots\ldots \quad (2)$$

Q_{out} is the heat released by the condenser to the ambient (J/kg), and h_3 is the enthalpy of the refrigerant at the outlet of condenser (J/kg). In the evaporator, the refrigerant absorbs the heat from the ambient or air around it. The heat absorbed Q_{in} can be calculated as:

$$Q_{in} = h_1 - h_4 \ldots\ldots \quad (3)$$

Meanwhile the performance of the machine is noted by COP written as:

$$COP = \frac{Q_{in}}{W_{in}} \ldots\ldots \quad (4)$$

Equations for calculating the heat transfer rate is as follows. First, equation for estimating the mass flow rate of dew is written as:

$$\dot{m}_d = \frac{m_d}{t} \ldots\ldots \quad (5)$$

$\dot{m}_d$ is the mass flow rate of the dew (kg/s), while m_d is the mass of the dew (kg), which is measured directly in the experiment using a digital scale, and t is the time for running the machine (s).

The total air mass flow rate can be determined using an equation below.

$$\dot{m}_t = \rho A V \ldots\ldots \quad (6)$$

$\dot{m}_t$ is the total air mass flow rate (kg/s), ρ is the air density (kg/m^3), A is the cross sectional area of inlet hole (m^2), V is the air velocity at the inlet (m/s). Then the dry air mass flow rate, $\dot{m}_{da}$ (kg/s) can be calculated as:

$$\dot{m}_{da} = \frac{\dot{m}_t}{w+1} \ldots\ldots \quad (7)$$

$$\dot{m}_v = w\dot{m}_{da} \ldots\ldots \quad (8)$$

w is the water vapour part in the air (kg$_v$/kg$_{da}$), which can be obtained using online psychrometric chart, http://www.hvac-calculator.net/index.php?v=2 [11], based on the inlet temperature (T_{in}) and inlet relative humidity abbreviated RH$_{in}$(%). $\dot{m}_v$ is the mass flow rate of the vapour (kg/s). The heat transfer rates consist of heat transfer rate from the dew, from the dry air and from the uncondensed vapour. The heat transfer from the dew can be obtained using the equation below.

$$Q_d = \dot{m}_d h_{fg} \ldots\ldots \quad (10)$$

Q_d is the heat transfer rate from the dew (W), and h_{fg} is the enthalpy of evaporation (J/kg) that can be obtained using a water saturated table based on the average of air temperature,

$$T_{av} = (T_{in} + T_{out})/2 \ \ldots\ldots \quad (11)$$

$T_{out}$is the temperature of the air at the exit (°C), T_{av} is the average temperature of the air (°C). The heat transfer rate from the dry air can be estimated as follow.

$$Q_{da} = \dot{m}_{da}(h_{in} - h_{out}) \ \ldots\ldots \quad (12)$$

Q_{da} is the heat transfer rate from the dry air (W), while h_{in} and h_{out} are the enthalpy of the air at the entrance and at the exit (J/kg), and taken from the online psychrometric chart, http://www.hvac-calculator.net/index.php?v=2 [11], based on the T_{av}.The last parameter is the heat transfer rate from the vapour, which can be estimated as:

$$Q_v = \dot{m}_v(h_{vin} - h_{vout}) \ \ldots\ldots \quad (13)$$

Q_v is the heat transfer rate from the vapour (W), h_{vin} and h_{vout} are the enthalpy of the vapour at the inlet and exit (J/kg), which is obtained from the online psychrometric chart, http://www.hvac-calculator.net/index.php?v=2 [11], based on the T_{av}. The total heat transfer rate, Q_t, is then:

$$Q_t = Q_d + Q_{da} + Q_v \ \ldots\ldots \quad (14)$$

3. Results and discussion

This study aims to determine the performance of the water harvester machine, namely the mass of condensed water, the total flow rate of air heat transfer to the condenser unit (evaporator), COP and efficiency of the condenser unit. Therefore, there are several stages that need to be analyzed both in terms of refrigerant and air.

The data obtained on the online psychrometric chart is the portion of water vapor in the air when entering the evaporator (w), the dry air enthalpy and the vapour enthalpy. These all are obtained by inputting the temperature and RH at the entrance and exit.

From the data obtained in the study, the following parameters can be calculated: mass flow rate of condensed water ($\dot{m}_d$), heat flow rate of dry air (Q_{da}), heat flow rate of dew or water (Q_d), heat flow rate of cooled steam (Q_v), mass flow rate of dry air ($\dot{m}_{da}$), mass flow rate of incoming vapour ($\dot{m}_v$), total mass flow rate of air ($\dot{m}_t$), and total heat flow rate absorbed by the evaporator (Q_t).

Refrigerant enthalpy is used in the calculation of the vapor compression cycle, where the enthalpy includes: enthalpy when exiting the evaporator (h_1), enthalpy when exiting the compressor (h_2), enthalpy when exiting the condenser (h_3), enthalpy when entering the condensing unit (h_4), h_1 and h_2 are searched in the superheated refrigerant 134a vapor table, while h_3 and h_4 have the same enthalpy can be searched in the saturated refrigerant 134a liquid temperature table. The data that are used to find the enthalpy in the thermodynamic table include: refrigerant pressure exiting the evaporator (P_1), refrigerant pressure exiting the compressor (P_2), refrigerant pressure exiting the condenser (P_3), evaporator outlet temperature (T_1), compressor outlet temperature (T_2) and condenser outlet temperature (T_3).

The results of the research of an air-water harvester machine with a vapor compression cycle are the amount of freshwater mass produced described in Figure 3, the heat transfer rate of the air indicated in Figure 4, and COP given in Figure 5. Data collection was carried out at the air velocity of 1.5 m/s, 3 m/s and 4.5 m/s.

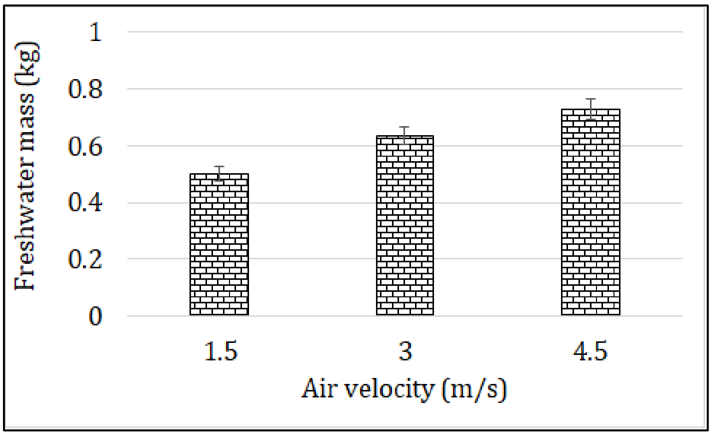

Figure 3 The freshwater mass at three different air velocities

The average water mass results shown in diagram 3 show that the largest water mass is produced by the air speed variation of 4.5 m/s, with water mass of 0.728 kg. Then successively continued with an air velocity of 3 m/s with water mass produced of 0.633 kg, and the last at the air velocity of 1.5 m/s, the water mass obtained is 0.500 kg. When compared with the results of Firdaus [12] with water mass of 0.622 kg produced at the air velocity of 5 m/s, the water mass produced from this study is greater than that of Firdaus [12]. Meanwhile, when the result is compared to the study of Fauzan [12], the study water mass is less, because Fauzan [13] obtained the water mass of 0.869 kg at the air velocity of 3 m/s. It can be seen in the comparison above between the results of this study and the results of the research of Firdaus [12] and Fauzan [13], that the higher the air speed entering the condensation box, the greater the mass of water condensed or produced, with the note that the air flowing through the condensation unit can still be condensed before exiting the box hole. At a speed of 4.5 m/s, this study produced the most water mass, this is because at a speed of 4.5 m/s the water vapor flowing through the condensation unit is more than at other speeds. Therefore, the mass of water at an air speed variation of 4.5 m/s has greater water mass compared to air speed variations of 3 m/s and 1.5 m/s. The condensation process occurs due to the transfer of heat from air with a higher temperature to the refrigerant with a much lower temperature through the walls of the condensation unit, thereby lowering the air temperature and reaching the dew point.

Furthermore, Figure 3 shows the trend of increasing fresh water mass as air velocity increases. Physically, higher air flow rates bring more water vapor to the condenser surface per unit time, thus increasing the potential for condensation. In forced convection, the convective heat transfer coefficient increases with increasing flow velocity, thus increasing the rate of heat transfer from the hot air to the cold surface as reported by Liu et al. [14]. The mass transfer of water vapor to the surface is also accelerated by the thinner boundary layer thickness in fast flow, similar to the relationship between Nusselt and Sherwood numbers that increase at higher Re. In other words, fast air reduces the convective and diffusive drag at the surface, allowing more vapor to condense into fresh water as explained by Liu et al. [14].

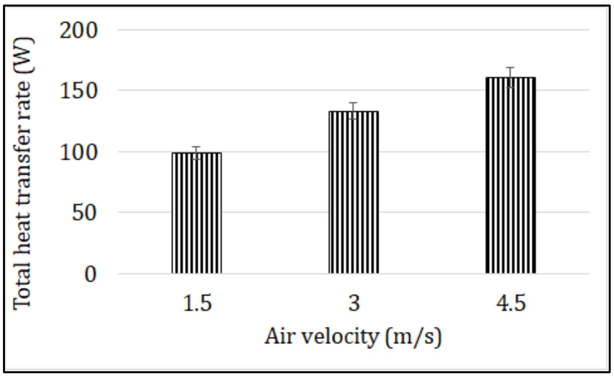

Figure 4 Total heat transfer rates

Figure 4 illustrates that the highest total heat transfer rate in this study occurs at an air velocity of 4.5 m/s, reaching 160.38 W. At air velocities of 3 m/s and 1.5 m/s, the total heat transfer rates are 133.29 W and 98.81 W, respectively. Compared to the findings of Firdaus [12], who reported a maximum heat transfer rate of 161.71 W at 5 m/s, the values in this study are slightly lower. However, when compared to Fauzan [13], whose maximum rate was 132.42 W at 4.5 m/s, the results of this study are higher. These variations can be attributed to differences in dry air and vapor properties across the studies. In this study, the superior performance at 4.5 m/s is likely due to the higher dry air and vapor content at that velocity, resulting in enhanced heat transfer.

The heat transfer rate increases as air velocity rises. The small error bars indicate minimal variation in the measurements, suggesting that the data are both stable and reliable. In convective heat transfer, higher air velocity increases the Reynolds number (Re), which in turn elevates the Nusselt number (Nu). This enhances the convective heat transfer coefficient, resulting in a greater total heat transfer rate. In essence, faster airflow promotes more efficient heat transfer between the surface and the air stream. This accelerated heat removal helps maintain lower surface temperatures.

In applications such as condensers or atmospheric water harvesters, maintaining a surface temperature below the dew point enables more effective condensation of water vapor. This graph supports earlier findings showing increased freshwater production at higher air velocities. A higher heat transfer rate improves the efficiency of the condensation process, yielding more water. Therefore, air velocity plays a crucial role in determining the performance of air-cooling and desalination systems.The observed positive correlation between air velocity and heat transfer rate aligns with the principles of forced convection, where increased airflow enhances thermal performance. However, it's important to consider the trade-off: higher air velocities require more energy input for fans or blowers. Thus, a comprehensive energy efficiency analysis at the system level is necessary to determine optimal operating conditions.

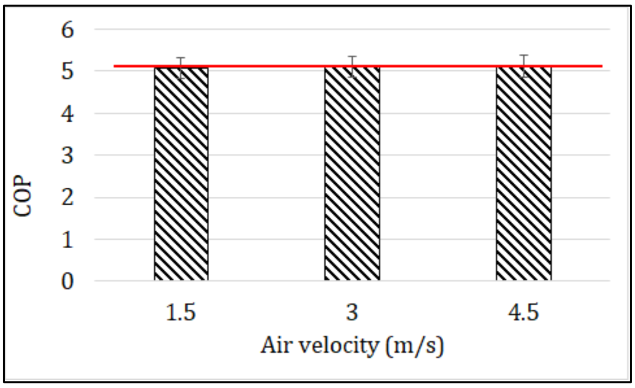

Figure 5 COP at three different air velocities

Figure 5 shows that the highest COP (Coefficient of Performance) is achieved at an air velocity of 4.5 m/s, with a value of 5.13. At 3 m/s and 1.5 m/s, the COP values are 5.10 and 5.07, respectively. However, based on the error bars, the differences among these values are statistically insignificant, as all error bars intersect a common horizontal line. This indicates that air velocity has no notable effect on COP in this setup.The consistency in COP values is attributed to identical system settings across all tests. Since COP primarily depends on the thermodynamic properties and states of the refrigerant, it is not significantly influenced by external air conditions, such as air velocity outside the evaporator.

COP is a key metric of energy efficiency in systems like heat pumps, refrigeration units, and thermal recovery devices—higher values represent better efficiency. Despite previous figures showing that increased air velocity improves heat transfer and freshwater production, the COP remains nearly constant around 5. This suggests that while higher air velocity increases output (e.g., more condensation or heat removal), it also requires greater energy input (e.g., from fans), resulting in a balanced ratio of output to input energy.Therefore, although the system delivers improved performance in terms of output with higher air velocity, its thermodynamic efficiency stays steady. The COP values observed indicate a well-functioning system, operating efficiently just below a benchmark value of 5, with minor losses potentially arising from factors like fan friction, thermal leakage, or non-ideal compression.

In conclusion, increasing air velocity enhances system output without compromising energy efficiency. However, for long-term operation, system designers should also consider the increased energy demands and potential mechanical wear from higher airflow rates. A comprehensive energy balance is essential when optimizing such systems.

4. Conclusion

This study evaluated the performance of an air-water harvester utilizing a vapor compression cycle, focusing on key parameters such as the mass of condensed water, air-side heat transfer rate, and COP in varying the air velocities (1.5 m/s, 3 m/s, and 4.5 m/s).

The findings indicate that increasing air velocity significantly improves both the mass of condensed water and the total heat transfer rate. At 4.5 m/s, the system achieved the highest water yield (0.728 kg) and heat transfer rate (160.38 W), outperforming comparable results from previous studies. This improvement is attributed to higher air and vapor content, enhanced convective heat transfer, and increased water vapor flux to the condenser surface due to thinner boundary layers at higher velocities.

Despite these performance gains, the COP remained nearly constant at approximately 5 across all velocities, with no statistically significant differences. This stability is due to consistent refrigerant settings and the fact that COP is mainly determined by the thermodynamic states of the refrigerant, not external air conditions.

Overall, the results demonstrate that higher air velocities improve the output performance (freshwater production and heat transfer) without degrading COP. However, these benefits must be weighed against increased energy consumption and potential mechanical wear from faster airflow. Therefore, for real-world applications, a holistic system-level energy and cost analysis is essential to identify the optimal operating conditions that balance performance and efficiency.

Compliance with ethical standards

Acknowledgments

The authors acknowledge the DRPM for funding the study through the WCR research schema with a contract number no. 030/E5/PG.02,00,PL/2023, and also the authors thank to the Mechanical Engineering Department, University of Mataram for the facilities.

Disclosure of conflict of interest

There is no conflict of interest in this work.

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