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Effect of inlet air velocities on freshwater mass and heat transfer rates in an air-water harvester 0.5 PK

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ABSTRACT

During the dry season, some regions experience a shortage of clean water due to drought. Air water harvesters utilize the principle of condensation to produce clean freshwater from humid air can be alternative to solve the drought. This device works by condensing water vapour in the air using an evaporator. The focus of this study was on the effect of air velocities on the freshwater production and heat transfer rates. This research was conducted experimentally using refrigerant R134a as the working fluid. The compressor used was a 0.5 HP rotary compressor. The inlet air velocities applied were 0 m/s, 1.5 m/s, and 3 m/s. The results showed that the highest average mass of water obtained was 3.73 kg using the air velocity variation of 3 m/s. Meanwhile, the total heat flow absorbed by the evaporator from the air was highest also at the air velocity variation of 3 m/s, which was 1238.22 W. Increasing inlet air velocities raises the freshwater production and heat transfer rates.

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1. INTRODUCTION

Water is a basic need for humans that is very important for daily life, both in villages and cities, especially when the dry season arrives in some areas of Indonesia experiencing a shortage of clean water or drought. Various ways have been carried out to obtain clean water such as seawater distillation, purification of dirty water or wastewater, water harvesting using nets and water harvesting using windmills. However, these various methods are less efficient and effective because each method has its own advantages and disadvantages. Therefore, a simple and ubiquitous air water harvester needs to be presented. The water harvesting tool can also be used for households. This water harvesting tool uses a refinement system or cooling machine, as explained by Mirmanto et al. (2024, 2024a), Tu et al. (2018), Dalai et al. (2017), Tu and Hwang (2020), Jarimi et al. (2020).

An air water harvester using a cooling machine is a tool that utilizes the principle of condensation to produce clean water from moist air. This tool works by condensing water vapour in the air using an evaporator. Research on this air water harvester machine has been carried out a lot, such as. Azari (2022), Winata (2021), Faroni (2022) and Prasetya (2022), Mirmanto et al. (2023, 2024b). However, the research has not been able to produce water in a large capacity and the results were not profitable yet because based on the study of Ahmad et

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al. (2022). If the comparison of the power used to the mass of freshwater production was higher than 1, the machine was not profitable.

Some of the factors that can affect the freshwater production from the air water harvester machine are RH, evaporator position, evaporator pressure, air temperature, natural or forced convection, air intake velocity and evaporator geometry. Some previous studies used forced convection were Prasetyo (2022), Fauzan (2022), Firdaus (2022), and Mari (2024), while those used free convection system were Winata (2021), Mirmanto et al. (2021), and Pangestu (2022). Prasetya (2022) carried out research using a forced convection system with an air velocity of 2.2 m/s and was able to produce 0.44 kg of freshwater for 7 hours. While Mari (2024) found much freshwater of 3.73 kg for 7 hours. The study conducted by Winata (2021) using a vertical position evaporator and natural convection system produced 0.5 kg of freshwater. Fauzan (2022) researched an air water harvester machine with inlet air speeds of 0 m/s, 1.5 m/s, 3 m/s and 4.5 m/s. The most water mass was produced at an inlet air velocity of 3 m/s, which was 0.869 kg for 7 hours. Meanwhile, Firdaus (2022) studied a an air water harvester machine with a shell-spiral condensation unit with an inlet air velocities of 3 m/s, 4 m/s, and 5 m/s. The highest water mass was produced at an inlet air velocity of 5 m/s. The difference of this study to the previous study was the evaporator. This study used a fabricated evaporator of AC 0.5 PK, while the previous used costume evaporators made by the researchers in the laboratory. Then the results of this study compared to the studies of Fauzan (2022) and Firdaus (2022) due to the same air velocity of 3 m/s and the same refrigerant of R134a.

2. RESEARCH METHODS

The research method used in this study is an experimental method with test equipment can be seen in figure 1. The tools and materials used in this study are 0.5 PK compressor, condenser, capillary pipe, evaporator, accumulator, thermal aluminium foil, anemometer, barometer, data logger, hygrometer, potentiometer, thermocouple, digital scale, compressor power meter, evaporator power meter, water storage container. The materials used were R-32 refrigerant and air. This study aims to determine the effect of incoming air velocities on freshwater mass and heat transfer rates in the 0.5 PK air water harvester machine.

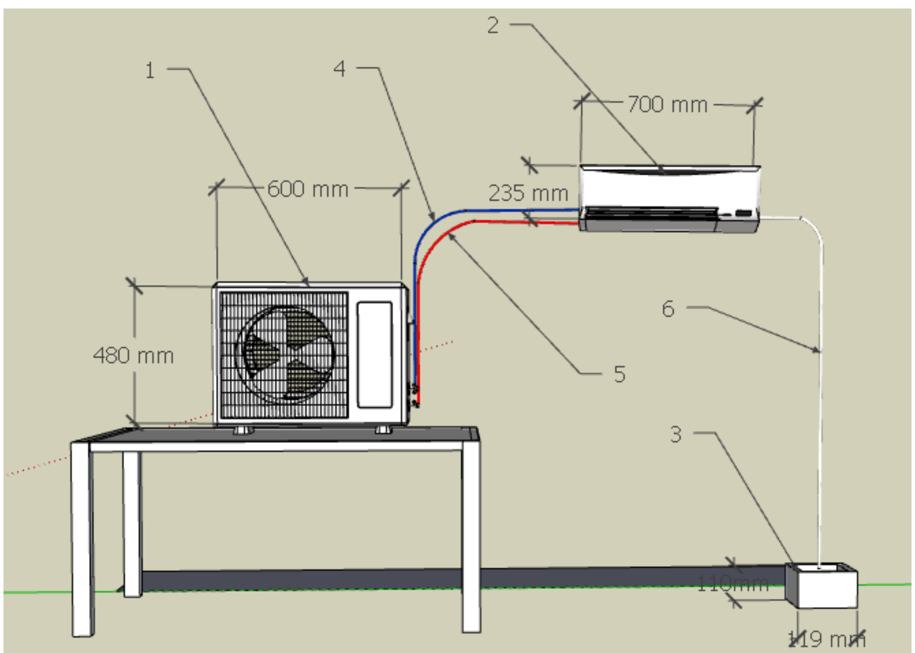

Figure 1. Water harvester machine scheme and parts. 1. Condenser, 2. Evaporator, 3. Bucket, 4. Inlet refrigerant pipe, 5. Outlet refrigerant pipe, 6. Drain pipe.

All temperatures were recorded using Applent AT4524 data logger with a temperature accuracy of ± 0.5°C. The inlet air velocity was measured using a digital anemometer model GM8902 with an accuracy of ± 0.1 m/s and the freshwater mass was measured using a digital scale model ACIS / BC-5000.

To analyze the effect of inlet air velocity some equations must be used. The total mass flow rate of the inlet air velocity is predicted using equation (1).

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$$\dot{m}_t = \rho A V \tag{1}$$

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

$$\dot{m}_{da} = \frac{\dot{m}_t}{1+w} \tag{2}$$

$\dot{m}_{da}$ is the mass flow rate of the dry air (kg/s), w is the part of water vapour in the air (kg_v/kg_{da}). w is obtained using T_i and RH_i inputted into online psychrometric chart, Free online Psychrometric Calculator (hvac-calculator.net). The mass flow rate of the vapour is then estimated by the equation below:

$$\dot{m}_v = w\dot{m}_{da} \tag{3}$$

$\dot{m}_v$ is the mass flow rate of the vapour (kg/s). The mass flow rate of the freshwater $\dot{m}_w$ can be calculated as:

$$\dot{m}_w = \frac{m_w}{t} \tag{4}$$

m_w is the mass of freshwater (kg) measured directly in the experiment. The heat transfer rates are determined as follows. The total heat transfer rate, in this study consists of heat transfer rate from dry air, heat transfer rate from the water vapour contained in the air, and heat transfer rate from the condensed water or freshwater. The heat transfer rate from the dry air can be calculated as:

$$\dot{Q}_{da} = \dot{m}_{da}(h_i - h_o) \tag{5}$$

$\dot{Q}_{da}$ is the heat transfer rate from the dry air (W), h_i and h_o are the enthalpy of the air at the entrance and exit holes (J/kg).

$$\dot{Q}_v = \dot{m}_v(h_{vi} - h_{vo}) \tag{6}$$

$\dot{Q}_v$ is the heat transfer rate from the vapour contained in the air (W). h_{vi} and h_{vo} are the enthalpy of vapour at the inlet and outlet (J/kg).

$$\dot{Q}_w = \dot{m}_w h_{fg} \tag{7}$$

$\dot{Q}_w$ is the heat transfer rate from the water (W), h_{fg} is the enthalpy of evaporation or condensation (J/kg). Then the total heat transfer rate from the air to the evaporator walls is

$$\dot{Q}_t = \dot{Q}_{da} + \dot{Q}_v + \dot{Q}_w \tag{8}$$

$\dot{Q}_t$ is the total heat transfer rate from the air to evaporator walls (W). Equations (1) to (7) can be obtained in Mirmanto et al. (2024b).

3. RESULTS AND DISCUSSION

The results of the inspection that have been carried out using a vapour compression cycle water harvester machine aim to determine the amount of freshwater mass produced (m_w), and the total heat absorbed by the evaporator from the air. Data collection was carried out for variations in air velocities of 0 m/s, 1.5 m/s and 3 m/s measured at the inlet. This test was carried out 3 times for each variation so that it took a total of 9 days.

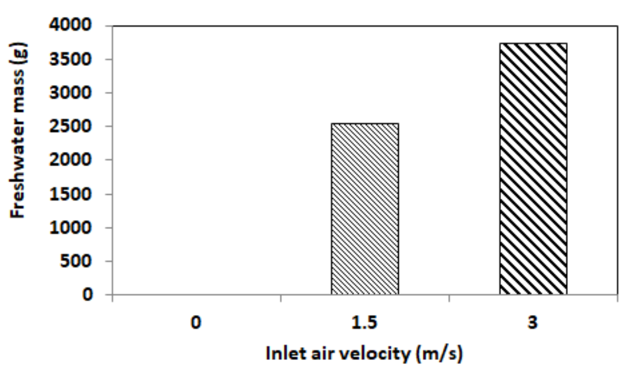

Figure 2. Freshwater mass of 3 variations of inlet air velocity

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Figure 2 shows that based on the inlet air velocity of 0 m/s with other inlet air velocities have a significant effect on the water mass produced. The average water mass produced occurred at an air velocity variation of 3 m/s, with an average water mass of 3.736 kg, an air velocity variation of 0 m/s with an average water mass of 0.007 kg, and an air velocity variation of 1.5 m/s with an average water mass of 2.535 kg, for each variation of air speed, 3 repeat attempts were carried out. The high air speed helps to increase the volume of air entering the evaporator so that the water vapor that can be produced also increases.

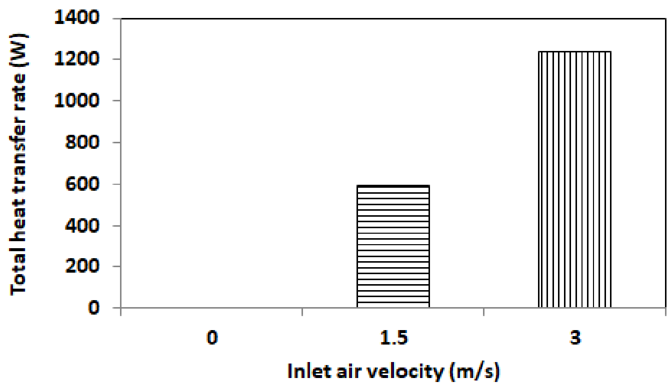

Figure 3. Total heat transfer rate absorbed by the evaporator from the air at 3 variations of the inlet air velocity

Figure 3 indicates indicate the experimental results of total heat transfer rates. Increasing the inlet air velocity raised the total heat transfer rate. This was due to heat transfer rate depending on the mass flow rate of inlet air. Increasing the inlet air velocity means levels the air mass flow rate, consequently raises the heat transfer rate, see equations (4-7).

Figure 4 indicates a comparison of freshwater production of previous study to this current study. Fauzan (2022) conducted a study on performance of water harvester water machines with parallel condensation units at various inlet air velocities. Fauzan (2022) resulted in 0.869 kg of freshwater at the air velocity of 3 m/s. Meanwhile, Firdaus (2022) performed a study of performance of an air-water harvester machine with a shell-spiral condensing unit at various inlet air velocities. At the inlet air velocity of 3 m/s, Firdaus (2022) obtained freshwater mass of 0.452 kg. In this current study, the mass of freshwater produced was 3.736 kg. This was due to the larger cross-sectional area compared to the previous study. In this study the cross-sectional area was 0.0177 m^2, while in Firdaus (2022) and Fauzan (2022) studies, the cross-sectional area was 0.00283 m^2 so that the volume of air entering the evaporator in this study was larger than the previous. Consequently, the current study obtained much freshwater production.

Figure 5 explains the total heat flow rate produced in the previous studies compared to this current study. Fauzan (2022) conducted a study on performance of water harvester water machines with parallel condensing units at various inlet air velocities. The results of Fauzan (2022) research showed that the total heat flow rate produced was 122.65 W using a variation in inlet air velocity of 3 m/s. Firdaus (2022)'study, entitled performance of a water harvester machine with a shell-spiral condensing unit at various inlet air speeds, showed that the total heat flow rate obtained was 118.47 W at the inlet air velocity of 3 m/s. As mentioned in the previous paragraph, the air inlet cross-sectional area of the current study was much larger than that of Fauzan (2022) and Firdaus (2022), therefore, the heat transfer rate of the current study was larger as the heat transfer rate was function of the air inlet mass flow rates.

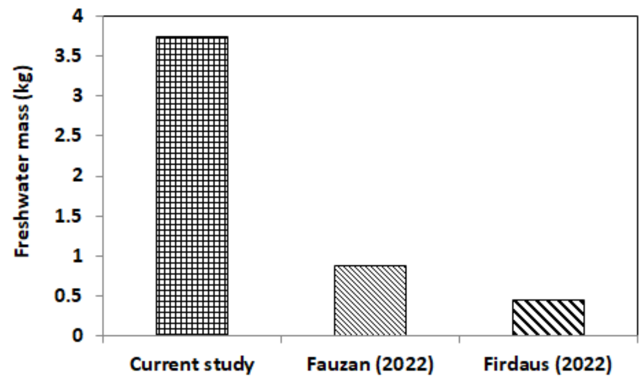

Figure 4 Comparison of freshwater mass with previous studies.

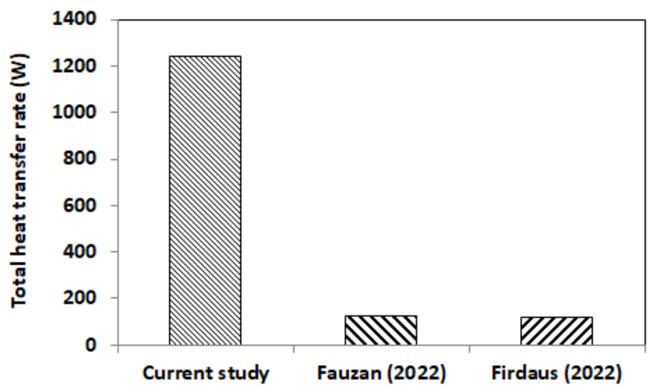

Figure 5. Comparison of the total heat flow rate ($\dot{Q}_t$) with previous research

4. CONCLUSION

Based on the results of research and analysis on the influence of air inlet velocities on the mass of freshwater produced and the total heat transfer rate from air to the evaporator in the 0.5 PK air-water harvester machine, some remarkable findings are as follows:

1. The highest freshwater mass of 3.73 kg is found at the inlet air velocity of 3 m/s.
2. The highest value of the total heat flow rate of 1238.22 W is found at the inlet air velocity of 3 m/s.
3. The current study results in much freshwater than previous studies at the same inlet air velocity of 3 m/s.
4. At the experimental conditions, for this current study, the inlet air velocity of 3 m/s is recommended and the next work will be using higher power of the machine.

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