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Performance of water harvester machine with parallel condensing unit at various inlet air speeds

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ABSTRACT: Water in human life has a very important function and must be fulfilled in daily life. During the dry season, parts of Indonesia experience drought and a clean water crisis. Various efforts are being made to meet the current need for clean water, such as by making dug wells, rainwater reservoirs or making equipment capable of producing water from the air. One of the efforts to obtain clean water is by presenting a tool called an air water harvester. The amount of water mass produced depends 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 water harvester machine at various variations in the intake air velocity. The engine performance in this study is the mass of water produced, COP, the amount of heat absorbed from the air, and the efficiency of the condensing unit. This research was conducted experimentally with R134a refrigerant working fluid. The compressor used is a rotary type 1 PK compressor. This study varied the air velocity entering the condenser unit, namely 0 m/s, 1.5 m/s, 3 m/s and 4.5 m/s. The results showed that the highest average water mass obtained was 0.869 kg/7 hours using a variation of air velocity of 3 m/s. Meanwhile, the highest COP is 4.91, obtained at variations of air velocity 0 m/s, the total heat absorbed by the condensing unit from the highest air occurs at variations in air velocity 4.5 m/s which is 132.42 J/s and the highest efficiency of 4.23% was obtained at 4.5 m/s air velocity.

KEYWORDS: Air water harvester , air temperature , Water mass, COP, Efisiensi

I. INTRODUCTION

Water is a crucial component for the development and growth of living things. Indonesia, a country located on the equator, has only two climates: the rainy season and the dry season. During the dry season, several regions in Indonesia experience drought or a clean water crisis. Consequently, these affected areas struggle to find water sources for their daily needs as explained by Gaol [1], and Atmoko [2].

This water scarcity problem must be resolved; one possible solution is to get water from the air. There are many ways to get water from the air, including: air-based water catchment nets, air-based water catchment windmills, and air-based water catchment machines using vapor compression systems. However, the drawback of air-based water catchment nets is that they cannot be used in all areas because they can only be used in highland areas with fog Taufani et al. [3], while air-based water catchment windmills can only be used in areas with high air intensity and require large costs or investments in the manufacture of tools and components. The most feasible effort to get water in any condition and location is an air-based water catchment machine using a cooling machine Mirmanto et al. [4-6].

Water capture methods using refrigeration machines or vapor compression systems are considered more practical because they can be applied across all regions. As is known, air contains water vapor, and even when dry, water vapor remains in the air, albeit in very small amounts as described by Mirmanto et al., [7-8]. Water capture is carried out through a dehumidification process. Air will experience a reduction in water content if the air temperature is lowered until its relative humidity reaches 100%. When the air reaches 100% relative humidity, the water vapor in the air will begin to condense. If the air temperature is lowered even lower, more water can be extracted from the air as reported by Irawan [9], and Monica [10].

Extensive research on machines producing water from air has been conducted, such as by Winata [11], Azari [12], Prasetya [13], and Faroni

[14]. However, these studies have not yet been able to produce water in large quantities. Winata's [11] study only produced 0.5043 kg of water, while Azari's [12], Prasetya's [13] and Faroni's [14] studies only produced 0.44 kg, 0.438 kg, and 0.369 kg, respectively. These results are even lower than Winata's [11] results. Therefore, further research is needed to improve this water production machine.

Several factors can influence the amount of dew produced, including relative humidity (RH), air temperature, evaporator pressure, evaporator position, natural or forced convection, inlet air velocity, and evaporator geometry. Winata's [11] study examined the vertical evaporator position and natural convection. Azari [12] and Faroni [14] conducted similar experiments, but with variations in the evaporator pipe diameter. Prasetya [13] conducted a different study, using a forced convection system with an air flow of 2.2 m/s, producing 0.44 kg of water over 7 hours. Because no one has yet studied the effect of inlet air velocity, which is a factor influencing dew production, the author is interested in exploring this issue.

Furthermore, in this study, the evaporator is named the condensing unit, as the evaporator in this machine functions to condense water vapor in the air. The purpose of this study is to determine the performance of a water harvester with a parallel condensing unit at various air velocities. The performance parameters are the mass of dew produced, the COP, the amount of heat absorbed from the air, and the efficiency of the condensing unit. The variations used in this study were the inlet air velocities of 0 m/s, 1.5 m/s, 3 m/s, and 4.5 m/s. Does increasing air velocity also increase the mass of water produced? This is what this study will seek to answer.

II. MATERIAL AND METHOD

The method used in this research is an experimental method that can be used to test the experimental equipment and materials.

The procedures of taking the data are as follows: turn on the data logger to record all temperatures required, and record the RH, and pressures manually. Then, turn on the air conditioner and set the air velocity to vary, for example, 4.5 m/s. Then, turn on the water harvester. Once all the engines are running, record the temperature, pressure, RH, velocity, compressor power, and water mass every hour. After 7 hours, the experiment was stopped. The experiment for each variation was repeated three times for making average values. Follow the procedure as described above for the other air velocity variations: 0 m/s, 1.5 m/s, and 3 m/s.

All equipment and materials were prepared in advance to avoid confusion when searching for them during the research. The equipment and materials used in this research include a compressor, condenser, condensing unit, capillary tube, thermocouple, digital thermometer, R-134a refrigerant, humidity controller, data logger, scale, water container, fan, and humidified air.

In this research, there are two types of variables: a) Dependent variables are variables that cannot be determined or controlled and are obtained during data collection and included in the analysis of the research results. The dependent variables in this research are: water mass, air heat transfer rate to the evaporator, COP, and evaporator efficiency. b) independent variables are variables that can be controlled or determined or changed according to the research objectives. The independent variables in this study are variations in the inlet air speed, namely (0 m/s, 1.5 m/s, 3 m/s and 4.5 m/s). The experimental apparatus is shown in Figure 1.

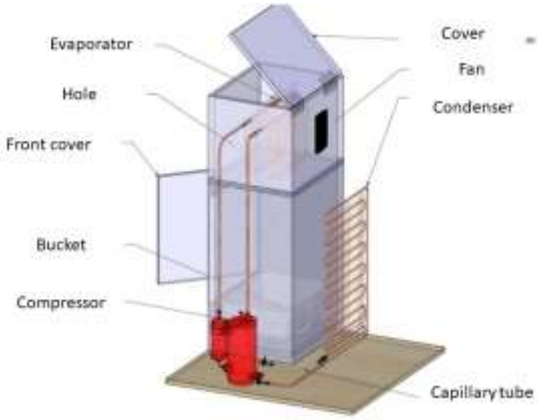

Figure 1. Schematic and position of the air-water harvester machine.

The parameter that can be presented directly in the form of graph is mass of freshwater. This parameter was obtained by measuring the mass of dew in the experiments. The mass of dew was symbolized by m_w. Meanwhile the heat transfer rate of the dew can be seen in equation (1). However, to calculate the heat transfer rate the mass flow rate of dew must be calculated using equation below:

$$\dot{m}_w = m_w / t \tag{1}$$

$\dot{m}_w$ is the mass flow rate of the dew (kg/s), while m_w is the mass of the dew measured directly in the experiment. The total air mass flow rate can be estimated using an equation below.

$$\dot{m}_t = \rho A V \tag{2}$$

$\dot{m}_t$ is the total mass flow rate (kg/s), ρ is the density of air (kg/m³), A is the area of inlet air (m²) and V is the air velocity (m/s) that can be measured directly in the experiments. The mass flow rate of the dry air is estimated using an equation below:

$$\dot{m}_d = \frac{\dot{m}_t}{1+W} \tag{3}$$

W is the part of water vapour in the air (kg_v/kg_d) obtained using online psychrometric chart, http://www.hvac-calculator.net/index.php?v=2 [15], based on the inlet air temperature and RH. The air vapour mass flow rate is then predicted using an equation below.

$$\dot{m}_v = W\dot{m}_d \tag{4}$$

$\dot{m}_v$ is the air vapour mass flow rate (kg/s). Then now the performance of the refrigeration machine used in the air water harvester machine is COP that can be obtained and Chengel and Boles [16]. The heat transfer rates and the efficiency can be calculated using equations in Mirmanto et al. [4-8].

III. RESULTS AND DISCUSSION

This research was to determine the effect of air inlet velocity on the amount of freshwater produced, COP, heat transfer rates, and the evaporator efficiency.

Data from the online psychrometric chart, free online psychrometric calculator [15] could be identified by inputting air temperature and the relative humidity entering the machine. The data obtained from the online psychrometric chart were W the air vapour part in the air entering the machine.

The data to obtain the COP are enthalpies at the entrance of compressor, at the outlet of compressor, at the entrance of evaporator, at the outlet of evaporator. To gain those all enthalpies mentioned above, a thermodynamic table containing refrigerant pressure and temperature must be used.

The mass of dew obtained is presented in figure 2. Data collection was carried out for each variation of air speed 0 m / s, 1.5 m / s, 3 m / s and 4.5 m / s. The data displayed in the graph is the data of the experiments of 4 variations. The mass of dew increases with the increase in the inlet air velocities, however, from 3 m/s to 4.5 m/s the effect of air inlet even goes down. This means that there is a maximum air inlet velocity that can result the highest mass of dew. Here, the maximum air inlet velocity is 3 m/s. The maximum freshwater mass obtained in this study is 0.869 kg. However, the mass freshwater obtained in this study is higher than that of Azari's [12], Prasetya's [13] and Faroni's [14].

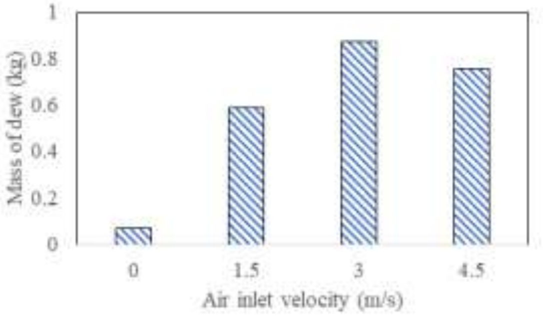

Figure 2. The mass of dew (freshwater) produced versus air inlet velocities.

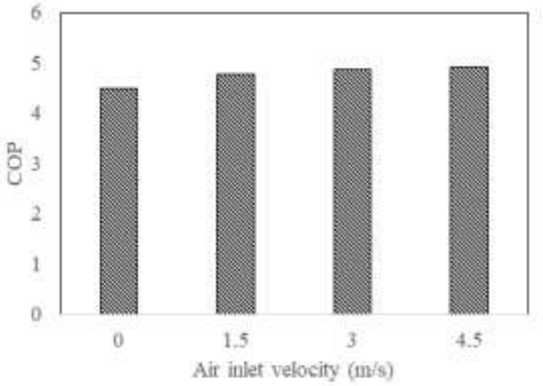

Figure 3. The COP versus air inlet velocities.

In Figure 3, the highest COP value is shown by the air velocity of 4.5 m/s with the COP value of 4.91, the air velocity of 3 m/s has a COP value of 4.87, and the air velocity of 1.5 m/s has a COP value of 4.76 and the air velocity of 0 m/s has a COP value of 4.48. COP is the ratio of the heat load per unit mass of refrigerant absorbed by the refrigerant in the condensing unit to the compressor work per unit mass of refrigerant. COP is found using the enthalpy values of refrigerant h_1, h_2 and h_4, the highest COP value at the air velocity variation of 4.5 m/s can occur because the heat absorption in the condensing unit is greater, and then the total heat absorbed is the highest one. The mass flow rate increases the heat transfer rate raises as the heat transfer rate is function of the mass flow rate. However, when 5% error is applied to the COP, there is no effect of increasing the inlet air velocity, except from 0 to 1.5 m/s.

Figure 4 shows that the highest total heat transfer rate of 132.42 W occurs at an air velocity of 4.5 m/s and the total heat transfer rate of 122.65 W, 75.89 W and 12.03 W happens at the inlet air velocities of 3 m/s, 1.5 m/s and 0 m/s. The air velocity of 4.5 m/s has the highest total heat transfer rate compared to other variations. This can happen because the air velocity of 4.5 m/s has the highest dry air and vapour values.

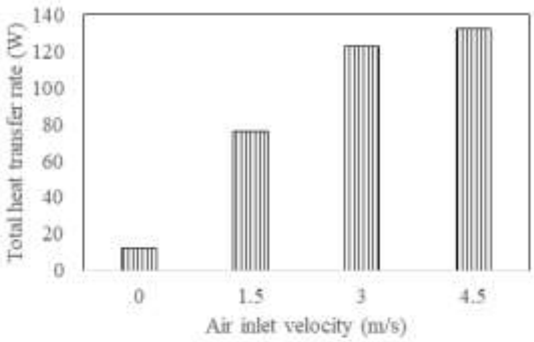

Figure 4. Total heat transfer rate versus inlet air velocity

The efficiency of the evaporator from 4 variations can be used to determine the performance of the machine by comparing the total heat flow rate absorbed by the evaporator with the heat flow rate absorbed by the refrigerant in the evaporator its self. The results are presented in figure 5.

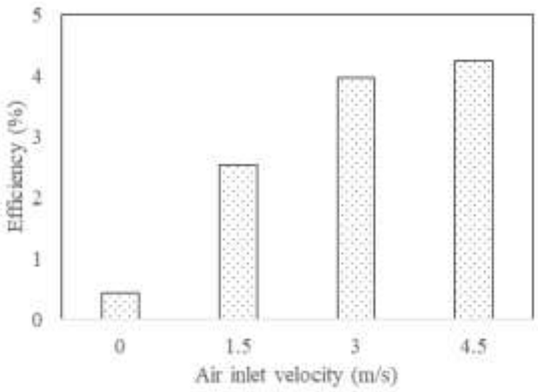

Figure 5. Efficiency versus inlet air velocity

The efficiency of the evaporator can be seen in figure 5. The highest efficiency occurs at an air velocity of 4.5 m/s with the efficiency of 4.23%, at the air velocity of 3 m/s the efficiency detected is 3.95%, while at the air velocity of 1.5 m/s and 0 m/s the efficiencies are 2.52% and 0.43%. Increasing the air velocity raises the efficiency. Meanwhile, efficiency is based on the total heat flow rate absorbed by the evaporator, not based on the mass of water produced alone. Even though the mass of water produced is large, but the total heat flow rate absorbed by the evaporator is small, so the efficiency is certainly small.

IV. CONCLUSION

Based on the results of research on the effect of the inlet air velocity on the mass of dew (freshwater) produced, the following conclusions can be drawn.

1. The results of the study indicate that the highest dew or freshwater mass occurred at an inlet air velocity of 3 m/s, with the freshwater mass of 0.869 kg.
2. The highest COP occurred at an inlet air velocity of 4.5 m/s, with COP of 4.91.
3. The highest total heat transfer rate absorbed by the evaporator occurred at an inlet air velocity of 4.5 m/s, with the total heat transfer rate of 132.42 W.
4. The highest efficiency of the evaporator occurred at an inlet air velocity of 4.5 m/s, with the efficiency of 4.23%.

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