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Effect of air velocities on the coil air water harvester performances

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Abstract:
Water in human life has a very important function and must be fulfilled in everyday life. During the dry season, some parts of Indonesia experience drought and a clean water crisis which results in scarcity and difficulty in drinking water. One solution that can be done to overcome this problem is to obtain water from the air using a device that is called air-water harvester. The amount of water mass produced depends on several variables such as RH, intake air temperature, air velocity, type of condensing unit and engine power. This study aimed to determining the performance of the air-water harvester machine at various intake air velocities. This research was conducted experimentally with R134a refrigerant as the working fluid and the evaporator was a coil arrangement. The compressor used was a rotary type 1/2 PK. The air velocities entering the condenser unit were 3 m/s, 4 m/s, and 5 m/s. The results showed that the highest water mass of 0.622 kg was obtained at the air velocity of 5 m/s. The highest COP total heat absorbed by the evaporator were also dicussed. Increasing the air velocity leveled the water production.

Keyword*: Air-water harvester; Coil evaporator; Mass of water production, Air velocity*

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I. Introduction

When the dry season arrives, several regions in Indonesia experience a clean water crisis. Every year the Gunung Kidul area, East Java, Central Lombok and NTT always experience a scarcity of clean water. The current problem of scarcity of clean water needs to be addressed. One solution that can be done is to obtain water that is not sourced from the ground, but from other sources. As you know, air contains water vapor. Unlimited air volume, allows water to be obtained from the air with no limit. There are many ways you can do to produce water from the air. One way to obtain clean water is to provide a tool called an air-water harvester. This tool converts water vapor in the air into dew so that the dew collects into water[1,2,3].

Atmoko[4] performed research using an Air Conditioner cooling system that works with a vapor compression cycle consisting of a 1.5 PK compressor, an evaporator in the form of a finned pipe and an air-cooled condenser type condenser, a capillary tube 0.028 inches in diameter and 40 cm long. The refrigerant used in this research is R22. The modifications applied to the research are using 3 fans which function to compress air with a power of 72.6 watts, cool the condenser with a power of 35.2 watts and dissipate condenser heat to the outside environment with a power of 66 watts. The highest water yield that can be produced by a machine that produces water from the most air is at a variation of the fan rotation speed of 350 rpm, which is 4.29 liters/hour. The research was conducted with an evaporator pressure of 68 psi.

Dirgantara[5] conducted research on making a water-producing device from the air using an evaporator that is parallel to the Air Conditioner cooling system with a power of 0.5 PK, and R-134a refrigerant. The average amount of water produced by the water-producing machine from the air in the vertical evaporator variation is 343.2 grams which is the result of the highest amount of water in the study. The evaporator used by Aerospace in this study is a vertical evaporator which has a length of 60 cm, a width of 32 cm and a diameter of 6.35 with an evaporator pressure of 40 psi.

Prasetya[6] had conducted a study entitled "The effect of the pressure of the condenser unit on the air-water harvester machine on the mass of water produced". This study examines the effect of evaporator pressure on the mass of water produced by parallel evaporators. The evaporator pressures varied were 30 psi, 40 psi and 50 psi with the air speed used being 2.2 m/s. The refrigerant used is environmentally friendly R134a. The compressor specifications used are compressors with a power of 1/2 PK. The results showed that the highest water mass was obtained at a pressure variation of 30 psi with an average mass of water for 7 hours/day, amounting to 0.438 kg. While the lowest average mass of water occurs at a pressure variation of 50 psi of 0.177 kg. The highest COP was obtained at 30 psi pressure variation of 25.29 and the lowest COP at 40 psi pressure variation was 10.84. The highest efficiency was obtained at 40 psi variation of 4.76% and the lowest efficiency at 50 psi pressure variation of 2.92%. The average inlet air temperature is 35.09˚C.

A previous study[1] examined the effect of the number of evaporators on water production and the performance coefficient of harvesting water from air. Water is obtained on the walls of the evaporator in the modes of free convection and condensation heat transfer. The dimensions of the evaporator are 480 mm × 285 mm × 6.35 mm. The evaporator is built using copper pipes arranged in parallel in an open box (open top and bottom) with a size of 500 mm × 500 mm × 500 mm. Refrigerant R134a is used as a working fluid. The experiment was carried out at a low pressure of 40 psi and a high pressure of 180 psi. On the outer wall of the evaporator, air flows naturally and some of the moisture in the air condenses. Three variations of evaporators were tested in case A (one evaporator), case B (two evaporators), and case C (three evaporators). Each evaporator contains 25 copper pipes and the length of each pipe is 285 mm. Maximum water production and evaporator efficiency achieved are respectively 0.51 L per day and 13%. Engine COP ranged from 5.2 to 13.3. Increasing the number of evaporators can increase fresh water production.

Faroni[7] investigated the effect of the diameter of the condenser unit pipe on the mass of water produced from the air-water harvester, in this study the evaporator was used from copper in a parallel shape and experiments were carried out with the working fluid refrigerant R134a. The compressor used is a 0.5 PK rotary type compressor. This study varied the diameter of the condensing unit pipe, namely 3.00 mm, 4.00 mm and 6.35 mm in diameter. The results showed that the highest water mass obtained was 0.369 kg/7 hours using a pipe diameter variation of 3.00 mm. Meanwhile, the highest COP, namely 13.28, was obtained for a pipe diameter variation of 3.00 mm and the total heat absorbed by the condensing unit from the highest air occurred at a pipe diameter variation of 3.00 mm, which was 52.10 W. The highest efficiency of the condensing unit was at variation in diameter of 6.35 mm is equal to 2.38%. The average inlet air temperature is 29.21°C and the average outlet air temperature is 26.13°C.

Azari[8] (2022) conducted a study entitled "The effect of the diameter of the evaporator pipe on the mass of water produced by a vapor compression system". This research was conducted experimentally. in this study the evaporator used is parallel. This machine works using refrigerant R134a with a vapor compression cycle. The compressor used is a rotary compressor with a power of 0.5 PK. Variations in this study are the diameter of the evaporator pipe, namely the diameter of 10 mm, 8 mm and 6.35 mm. The results showed that the machine that produces water from air can work well. The highest COP is found in a variation of 8 mm in diameter, which is 11.82, then for the total heat absorbed by the evaporator from air, the highest occurs in a variation of 8 mm in diameter, which is 74.84 W. , then the highest evaporator efficiency value of 3.09% was obtained with a diameter of 8 mm and finally the most water mass produced was 0.44 kg with a diameter of 8 mm.

The evaporator used in this study is called a condensing unit, which is a coil (spiral) evaporator and has been made by previous researchers in the lab. The fan is placed at the top of the evaporator which functions to circulate air and the fan speed is set 3 m/s 4 m/s 5 m/s. This machine works by means of air from the environment entering through the top air hole and the air entering the condensing room where there is a condensing unit in it. The room is called the condensation room because the process of condensing water vapor carried by the air occurs in that room. The air hits the walls of the condensing unit where the temperature is low so that some of the moisture in the air condenses, and the dewdrops drip into the water bath. Then the air flows out through the bottom hole.

The condenser used in this study is forced convection in which the flow of fluid to cool the condenser is caused by external devices, such as fans. The condenser is made by the lab itself, which is parallel and made of copper pipes measuring 6.35 mm. Previous researchers mostly used finned and parallel tubular evaporators (condensing units), while shell and spiral shaped condensing units have not been investigated. Therefore, this study examines air-water harvester machines with shell and spiral condensing units with variations in the inlet air velocity. The airspeeds varied were 3 m/s, 4 m/s and 5 m/s.

II. Materials And Methods

The schematic experimental facility is presented in figure 1. The facility contains a condenser, an evaporator, a compressor, and an expansion valve (capillary tube). Dependent parameters were variables that could not be adjusted, and their values were obtained at the experiments and included in data analysis. The variables included were the mass of condensed water, and the temperature of the air entering and leaving the evaporator. The independent variables were variables that could be regulated or could be changed according to the research objectives. The independent variables in the study were 5 turns, 10 turns, and 15 turns. All temperatures were measured using K-type thermocouples with an uncertainty of ± 0.5°C, while the pressures were measured using pressure gauges with a resolution of 5 psi. The mass of the drinking water was measured using a digital balancer with an uncertainty of ± 1 g.

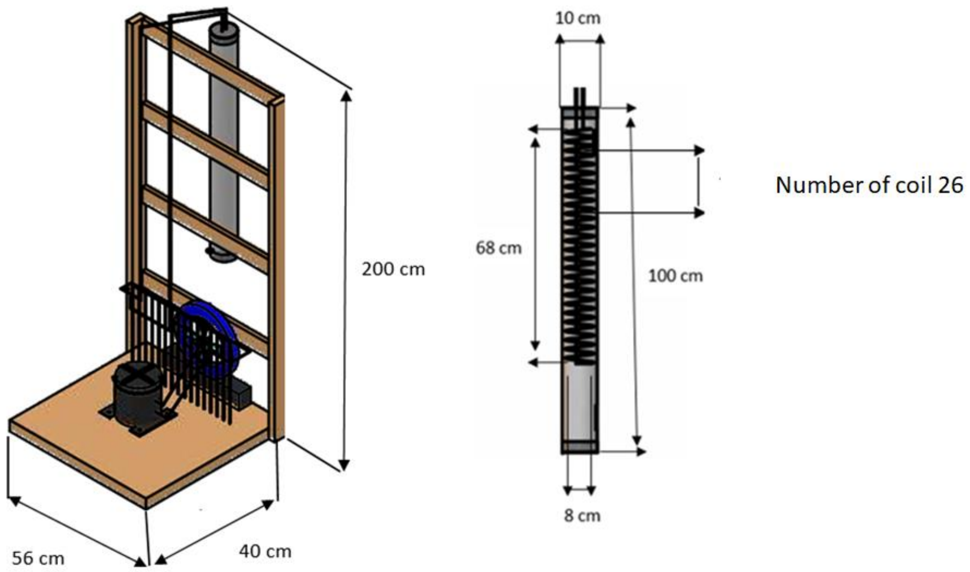

Figure 1. The experimental facility

In figure 1, the ambient air flowed through the condenser due to a fan. It was a forced convection mode to remove heat from the condenser. Similarly, air flowed through the evaporator was also forced convection due to a fan. This was meant to increase the amount of air coming into the evaporator (condensation unit). The air velocity was measured directly using a digital anemometer series GM816.

The electric power needed by the compressor is not only for the vapor compression process, but also to overcome mechanical constraints, friction, steam leaks, cooling processes, and others. These constraints will reduce the power of the compressor shaft. To determine how much electrical power is needed for the compression process as follows:

$$P_c = VIP_F \tag{1}$$

P_c is the electrical power of the compressor power (W), V indicates the voltage that measured directly in the experiments (volt), I is the current that was also measured in the experiment (ampere). P_F is the power factor, its value is usually in the range of 0.7 to 0.9, however, in this study the power factor was measured directly in the experiments. Cengel dan Boles[9] explained that the compresor work was the difference between h_2 and h_1 as described here.

$$W_{in} = h_2 - h_1 \tag{2}$$

h_2 and h_1 are enthalpies (J/kg) at the State 2 and 1, see figure 2. The condensation process takes place from State 2 to State 3 which occurs in the condenser. Process 2-3 occurs at constant pressure, and the amount of heat energy released during this process is the enthalpy difference between States 2 and 3. As explained by Cengel and Boles[9] the amount of heat energy released by the condenser (Q_{out}) can be calculated by the equation:

$$Q_{out} = h_2 - h_3 \tag{3}$$

The evaporation process takes place from State 4 to State 1 which occurs in the evaporator. During process 4-1 the refrigerant enthalpy rises due to heat absorption from the outside air around the evaporator and causes a phase change of the refrigerant to become saturated vapor at the State 1. The amount of heat energy absorbed is the same as the enthalpy difference between State 1 and State 4. As explained by Cengel and Boles[9], the amount of heat per unit mass of refrigerant absorbed by the evaporator can be calculated by the equation:

$$Q_{in} = h_1 - h_4 \tag{4}$$

Cengel and Boles[9] explained that the *COP* of a vapor compression cycle machine was the ratio between the energy of refrigerant absorbed by the refrigerant in the evaporator and the work of the compressor. The *COP* value of a vapor compression engine can be calculated by the equation (5):

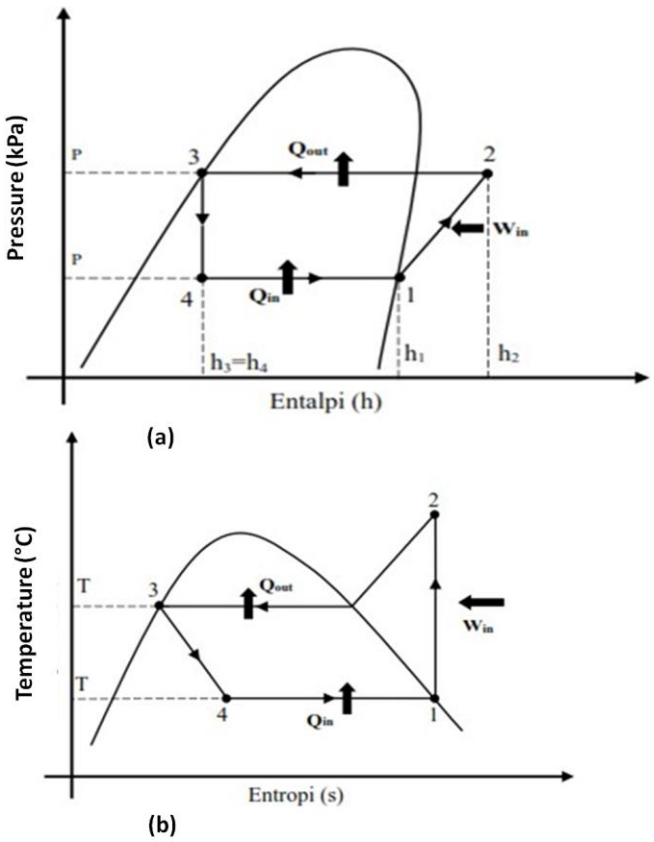

Figure 2. The ideal cycle; (a) P-h diagram and (b) T-s diagram

$$COP = \frac{Q_{in}}{W_{in}} \tag{5}$$

Mirmanto[1] explained that the refrigerant mass flow rate $(\dot{m}_{ref})$ represented the amount of refrigerant circulated per unit time and was calculated by the equation (6):

$$\dot{m}_{ref} = \frac{P_c}{W_{in}} \tag{6}$$

Mirmanto[1,2,3] explained that the mass flow rate $(\dot{m}_w)$ of condensed water could be calculated using the equation:

$$\dot{m}_w = \frac{m_w}{t} \tag{7}$$

t is the total time of the running machine (s). Gaol[10] explained that the amount of water vapor condensed could be calculated using equation (8):

$$m* = m_1^* - m_2^* \tag{8}$$

$m*$ is the part of water vapour that condense on the evaporator wall ($kg_{water\ vapor}/kg_{dry\ air}$). m_1^* represents the part of water vapour in the air entering the machine ($kg_{water\ vapor}/kg_{dry\ air}$), and m_2^* is the part of water vapor in the air exiting the machine ($kg_{water\ vapor}/kg_{dry\ air}$). For air flow using a fan, the total air mass flow rate can be calculated using the equation (9):

$$\dot{m}_a = \rho AV \tag{9}$$

$\dot{m}_a$ is the total air mass flow rate coming into the machine (kg/s), ρ is the density of the air (kg/m³), A is the cross sectional area (m²), and V is the air velocity coming to the machine (m/s).

$$\dot{m}_a = \dot{m}_v + \dot{m}_{da} \tag{10}$$

$\dot{m}_v$ is the mass flow rate of water vapour entering the machine (kg/s), $\dot{m}_{da}$ represents the mass flow rate of the dry air enteraing the machine (kg/s). The mass flow rate of the vapour is given by

$$\dot{m}_v = m_1^* \dot{m}_{da} \tag{11}$$

$$\dot{m}_a = m_1^* \dot{m}_{da} + \dot{m}_{da}$$

$$\dot{m}_{da} = \frac{\dot{m}_a}{m_1^* + 1} = \frac{\rho AV}{m_1^* + 1} \tag{12}$$

The total heat absorbed by the evaporator $(\dot{Q}_t)$ is then equals to an equation written in Mirmanto[1,2,3] .

III. Results and Discussion

The experimental results were processed and displayed in the form of graphs. The results of the tests that had been carried out were the amount of water production, COP, and the total heat transfer from the air. They were presented and discussed here. The following 3 graphs are displayed, e.g. the amount of water produced (figure 3), the coefficient of performance (*COP*) given in figure (4), and the total heat absorbed by the evaporator from the air($\dot{Q}_t$) described in figure (5).

The water production is presented in figure 3. The effect of air velocities on water production was clear. At the 3 m/s, the water production was 0.452 kg, while at the 4 m/s of air velocity, it was 0.531 kg, and at the air velocity of 5 m/s, the water production of 0.622 kg. Hence, the trends of water production relating to the air velocities increased with the air velocity. Compared to the previous studies, e.g. Mirmanto[1], Winata[11], the study resulted in higher amount of water production. However, the previous tudies were in free convection mode, while this study was in forced convection mode.

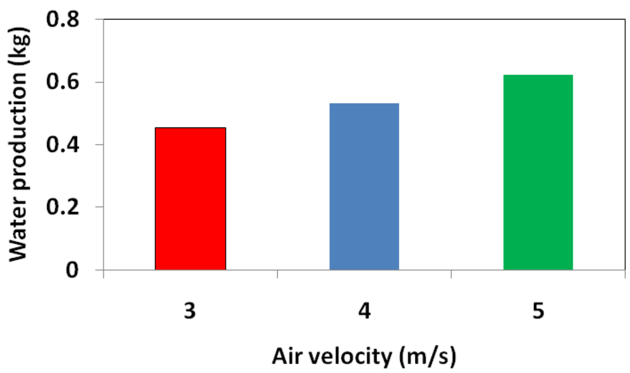

Figure 3. Water production versus ar velocity

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The performance of the machine could be seen from *COP*. The experimental *COP* is given in figure 4 for the three cases. From the *COP* parameter, the effect of air velocity on the *COP* was clear. It increased with the increased in the air velocity. In figure 4, the highest COP was found at air velocity of 5 m/s with a total average *COP* of 16.26, at the air velocity of 4 m/s, the total average *COP* was 15.48, and the lowest COP occured at the air velocity of 3 m/s with a total average *COP* of 15.15.

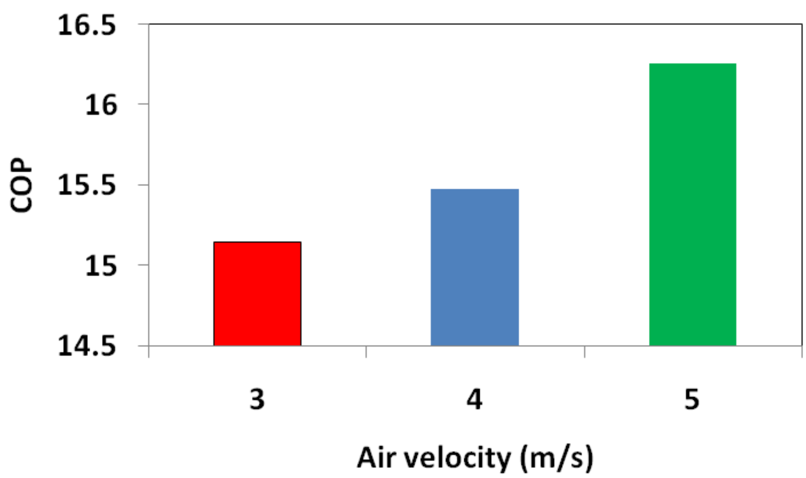

Figure 4. COP versus the air velocity

Based on figure 5, the total heat transfer rate increases with air velocities. Higher air velocity meant that the amount of air entering the machine was larger. It caused the increase in sensible and laten heat transfer. Therefore, the water production and the total heat transfer also increased.

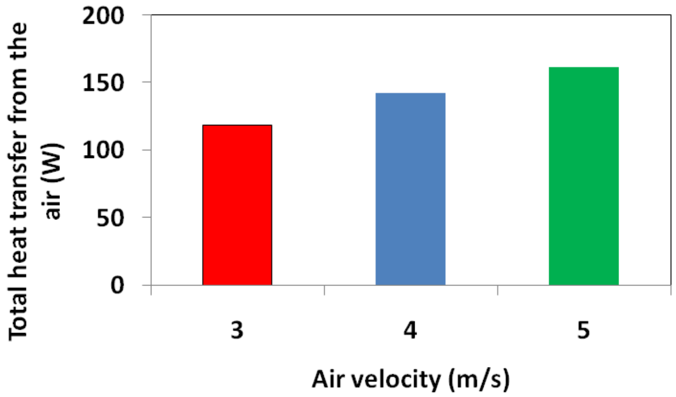

Figure 5. Total heat transfer from the air to the evaporator

IV. Conclusion

The study of the effect of the air velocities on the coil air water harvester performances at ambient conditions was performed. Some remarkable findings can be drawn as follows: the water production obtained in this study is still low. The maximum water production gained in this study is 0.622 kg. It needs further comprehenship studies. Increasing air velocities elevates the water production and the total heat transfer rate from the air. However, It needs study with higher air velocities to know the optimum air velocities for the machine.

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