IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 21, Issue 4 Ser. 1 (July. – August. 2024), PP 51-55
www.iosrjournals.org

The Effect Of Fan Location On The Performance Of An Air-Water Harvester Machine With Three Coil Evaporators

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Abstract:
During the dry season, several areas in Indonesia such as East Java, NTB and NTT experience a clean water crisis. One way to overcome the problem of the clean water crisis is to make a machine that harvests water from the air (air-water harvester). This study uses 3 evaporators to increase the freshwater production. The positions of the fans are at the entrance and at the exit. The diameter of the copper pipe used to make the evaporator is 6.35 mm, the coil diameter is 80 mm and the number of coils is 26 per evaporator, and the inlet air speed used in this study is 5 m/s which is the same for all fan locations. The research results show that the highest water mass and the total heat transfer rate are 1.003 kg for 7 hours and 267 W obtained for the fan position at the inlet (air is pushed into the machine).

***Keyword**: Air-water harvester; frehwater production; fan location; total heat transfer*

Date of Submission: 22-07-2024 Date of Acceptance: 02-08-2024

I. Introduction

Water is a basic need of every living thing that is very important and must be fulfilled in everyday life. At present, the existence of clean water sources in the ground is very difficult to obtain especially urban areas. Some cities in Indonesia have polluted land because on the surface there is a lot of household and industrial waste so that polluted surface water seeps into the ground. Also in Indonesia in dry season, several areas experiencing clean water crises. Many methods to obtaine clean water such as distillation and RO. However, for regions where there is no water at all, those mwthods cannot be utilized. One way to overcome this problem is to present a freshwater producing device from the air called an air-water harvester machine[1-5].

Air-water harvesters have many models such as harvesting water from the air using nets[6,7], harvesting water from the air using windmills[8] and harvesting water from the air using cooling machines[9]. The easiest and simplest and can be used anywhere is a water harvester using a cooling machine[1-5, 9]. Air-water harvester machines using cooling machines have been widely researched such as by Winanta [10], Prasetyo[11], Faroni[12], and Ramadhan[13].

Prasetya[11] had conducted a study of the effect of the pressure of the condenser unit on the air-water harvester machine on the mass of water production. 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.

Faroni[12] 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[14] (2022) conducted an experimental study of 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.

However, the research that has been done has not been able to produce water in much capacity. The Ramadan[13] study only produced 0.977 kg/7 hours of water, while Mirmanto[1], Winata[10], Prasetya[11], and Faroni[12] research was only able to produce 0.5043 kg, 0.51 kg, 0.4384 kg and 0.369 kg for 7 hours. These results were even less compared to Ramadan[13]. Therefore, this water-producing machine still needs to be developed to increase the production of water produced.

Some factors that affect a lot of the mass of water produced are the RH of the inlet air Irhami[15], the temperature of the inlet air Hendra[16], the construction of the evaporator, the area of the evaporator[1], the diameter of the evaporator pipe Faroni[12], and the speed of the inlet air Fisrdaus[17]. While the variations carried out in this study are fan positions. When the fans were placed at the entrance meninag that air was pushed into the machine, while when the fans were palce at the exit meant the air was such from the machine. The air velocity was kept constant at the inlet at 5 m/s.

II. Materials And Methods

The schematic experimental facility is presented in figure 1. The facility contains a condenser, coil evaporators, a compressor, an expansion valve (capillary tube), condensation box and a bucket. The air was flowed by fans that were placed at the entrance (Case A) and fans were palced at the entrance and exit (Case B), and the fan was placed at the exit (Case C). 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 freshwater was measured using a digital balancer with an uncertainty of ± 1 g.

In figure 1, the ambient air flowed through the condensation box due to fans. It was a forced convection mode to heat transfer from the air to evaporator. The forced convection mode was meant to increase the amount of air coming into the evaporator inside the condensation box. The air velocity was measured directly using a digital anemometer series GM816. The electric power needed by the compressor was 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. The shape of evaporator is shown in figure 2.

To examine the air-water harvester performance, some equatios below are required. The perfromances are indicated by the freshwater mass and the total heat transfer rate. Mirmanto[1-5] explained that the mass flow rate $(\dot{m}_w)$ of condensed water could be calculated using the equation:

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

t is the total time of the running machine (s). Gaol[18] explained that the amount of water vapor condensed could be calculated using equation (2):

$$w^* = w_1 - w_2 \tag{2}$$

w^* is the part of water vapour that condense on the evaporator wall ($kg_{water\ vapor}/kg_{dry\ air}$). w_1 represents the part of water vapour in the air entering the machine ($kg_{water\ vapor}/kg_{dry\ air}$), and w_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 (3):

$$\dot{m}_a = \rho A V \tag{3}$$

$\dot{m}_a$ 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).

$$\dot{m}_a = \dot{m}_v + \dot{m}_{da} \tag{4}$$

$\dot{m}_v$ 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

$$\dot{m}_v = w_1 \dot{m}_{da} \tag{5}$$

$$\dot{m}_a = w_1 \dot{m}_{da} + \dot{m}_{da}$$

$$\dot{m}_{da} = \frac{\dot{m}_a}{w_1 + 1} \tag{6}$$

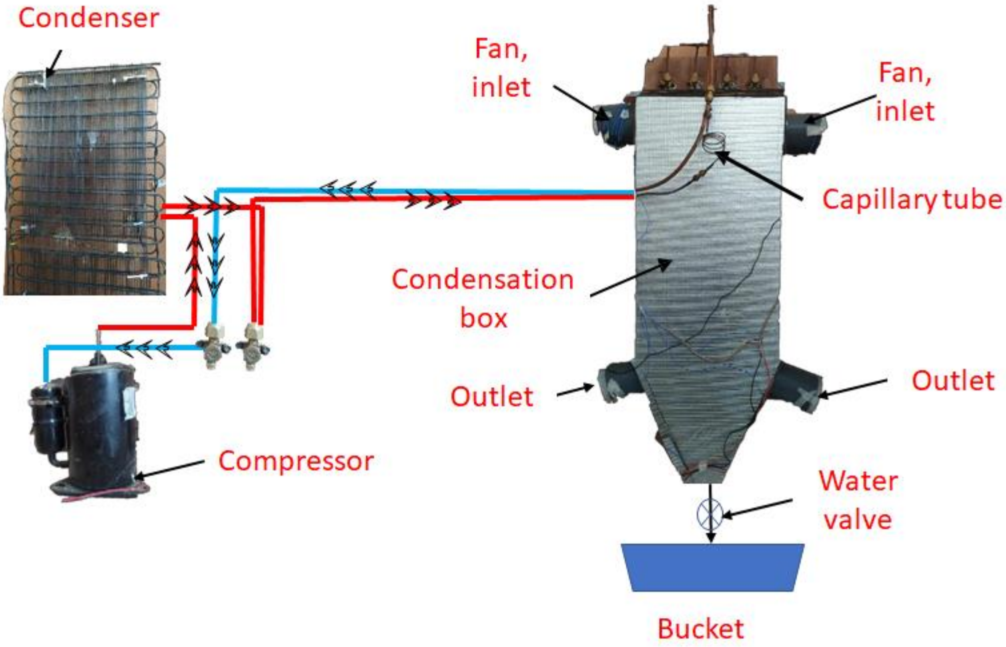
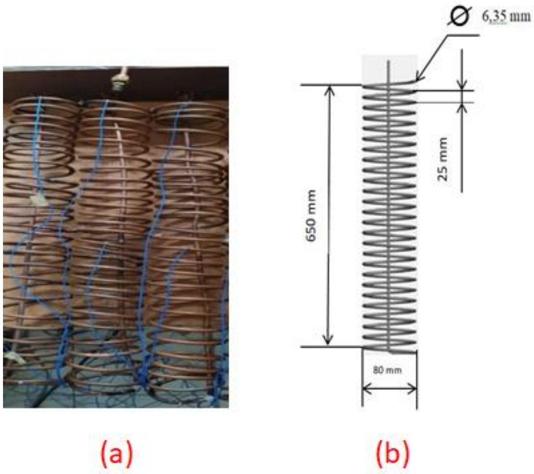


Figure 1. The experimental facility



(a) (b)

Figure 2. The shape of evaporator; (a) a photograph of evaporator, (b) dimension of the evaporator

The total heat absorbed by the evaporator($\dot{Q}_t$) is then equals to the heat transfer rate from the dry air, water vapour and condensed water that can be estimated as

$$\dot{Q}_t = \dot{Q}_{da} + \dot{Q}_v + \dot{Q}_w \tag{7}$$

$$\dot{Q}_{da} = \dot{m}_{da}(h_i - h_o) \tag{8}$$

$$\dot{Q}_v = \dot{m}_v c_{pv}(T_i - T_o) \tag{9}$$

$$\dot{Q}_w = \dot{m}_w h_{fg} \tag{10}$$

Equations (7-10) can be obtained in Mirmanto[1-5]. Meanwhile, $\dot{Q}_{da}$ is heat transfer rate from the dry air (W), $\dot{Q}_v$ represents the heat transfer rate from the water vapour (W) and $\dot{Q}_w$ is the heat transfer rate from the condensed water (W). h_1 and h_o are the enthalpies of the dry air at the inlet and outlet positions (J/kg). T_i and T_o are the temperatures of the air at the inlet and outlet locations (°C). c_{pv} is the heat capacity of the vapour (J/kg°C) and h_{fg} is the enthalpy of evaporation or condensation (J/kg).

III. Results And Discussion

The experimental results were processed, analyzed and displayed in the form of graphs. The results of the tests that had been carried out were the amount of freshwater productions, and the total heat transfer from the air. They were presented and discussed here to answer the questions of the study. The following 2 graphs are displayed, e.g. the amount of water produced (figure 3) and the total heat absorbed by the evaporator from the air($\dot{Q}_t$) described in figure (4). The amount of the freshwater productions were measured directly in the experiments using a digital scale with a resolution of 1 g.

The water production is presented in figure 3. The effect of the fan location on the water production is clear. Case A resulted in 1003 g, Case B produced 715 g, and Case C gave 572 g for 7 hours. Case A resulted in higher freshwater production was due to the compressed air. At Case A, the air was compressed inside the condensation unit because air was restricted by the coil evaporators inside the condensation unit. Hence, the air flowed over the coils with slightly lower velocity inside the condensation unit. Consequently, much air water vapour contacted with the coil evaporators, so the condensed water was larger. At the Case C, the air was suck by the fan at the exit. It meant that there was low restriction for the air to flow. Consequently, there was less air water vapour contacting the coil walls. Therefore, the condensed water produced was less. This finding agreed with that of Ramadhani[13]. However, Ramadhani[13] used parallel pipe evaporators and the machine was arranged in horizontal position.

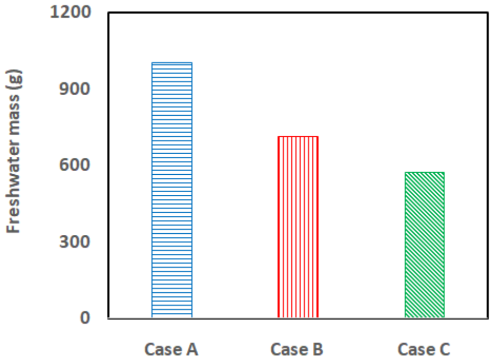


Figure 3. Water production versus cases

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Based on figure 4, the total heat transfer rate decreases with the cases. Compressed air as belonged to Case A meant that the much air entering the machine touched the cold surface of coil evaporator, so the greater heat transfer rate occured. Also, the compressed air caused much air water vapour condensed, therefore, the heat transfer rate especially latent heat increased. Case C resulted in less heat transfer rate because the air flowed freely sucked by the fan at the exit. It caused the air no time to contect with the coil walls inside the condensation unit. As a result, Case C produced low freshwater as well as low heat transfer rate. Case B resulted in higher heat transfer rate compared the Case C, because at Case B, the air still got restriction by the coil evaporators due to the fan at the entrance. Hence, the restriction gave little bit higher freshwater mass and heat transfer rate compared to the Case C. Again this phenomena was also found by Ramadhani[13]. The Case A results in higher freshwater mass and heat transfer rate.

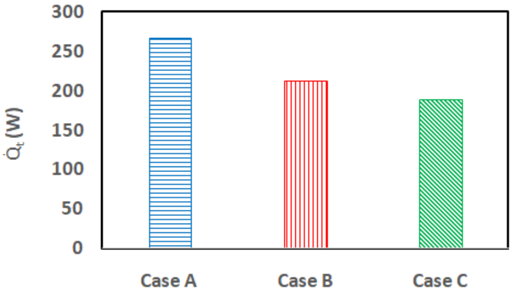

Figure 4. Total heat transfer from the air to the evaporator

As the purpose of this study was to increase the freshwater mass, then a ratio of energy used to the freasswater production should be presented. The ratio of energy used to the freshwater production is noted EUR in kWh/kg. The electricity energy was obtained by total electrical power consumed multiplied by the hour of running the machine and devided by the freshwater mass in kg. This is one way to know that the machine is effective or not. When the EUR is les than 1, the machine is good. The EUR of this study is presented in figure 5. Figure 5 indicates that the machine is not effective yet because the EUR is higher than 1 for all cases. Then it needs further improvements to obtaine EUR of at least 1. However, as explained above that the Case A is better because it has the lowest EUR compared to the others.

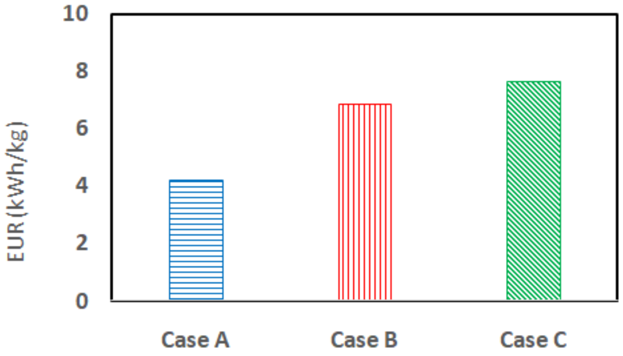

Figure 5. The EUR for the three cases

IV. Conclusion

The study of the effect of the fan location 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 1003 kg attained by the Case A. The total heat transfer rate obtained is 267 W obtaine by the Case A. It needs further comprehenship studies or improvements to the machine. The best position of the fan is at the entrance.

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