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Performance of Air-Water Harvester Machine for Cooling Drinking Water

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Abstract:
The cold air coming out from an air-water harvester machine has not been utilized yet. Therefore, this study focused on ability of the air-water harvester machine to cool drinking water.
This research was conducted experimentally with variations of drinking water mass. The drinking water mass variations studied consisted of 0 kg of drinking water (empty drinking water chamber), 1.5 kg and 3 kg of drinking water. This machine used-R134a refrigerant and a compressor of 1/2 PK. The evaporator used was a coil shape with the coil number of 18, coil diameter of 12 cm, the total pipe length of 7.14 m and the pipe diameter of 6.35 mm. The evaporator pressure was kept a constant pressure of 40 psi. The mass of refrigerant fed into the machine was 190 g.
The results showed that at mass of 0 kg water, the air-water harvester machine was able to cool the drinking water and the chamber, but at masses of 1.5 kg and 3 kg, the machine was unable to cool the drinking water and the chamber. The ability of the machine to cool the drinking water and the chamber was indicated by the value of dE/dt and the chamber temperature. The coefficient of performance (COP) as an additional result of this study was 11.67. The maximum mass of water produced from the machine was 238 g for 7 hours.
The machine could not produce chamber temperatures of below 25°C. This means that the machine is not able to cool drinking water. The machine is only specialized to produce water from the water vapor in the air.
Key Word*: Air-water harvester; Drinking water mass; Cooling ability; COP*

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I. Introduction

The cooling system has a very important role in people's lives today. In Indonesia, which has a tropical climate, almost every home can be found equipment that uses a cooling system. In households, cooling systems are used in equipment such as air conditioners, refrigerators, freezers and dispensers that use refrigerant as a cooling medium. This equipment has a function to store various types of food, beverages, vegetables and fruits to make them last longer and stay fresh.

Refrigerators are used to store various kinds of ingredients for cooking, food, drinks and medicines. Based on the regulation of the Food and Drug Supervisory Agency of the Republic of Indonesia regarding guidelines for good food retailing in food storage, it is explained that the recommendations for storing dry food such as meat, fruit, dried vegetables, seeds and their processed products, fats, oils and canned food and beverages at temperatures between 10˚C and 20˚C[1]. However, none of the cooling machines functioned as a water producer.

Cooling machines to produce water already exist, but are only devoted to producing water and are not used to cool goods or drinks. Research on cooling machines to produce water has been carried out by several previous researchers. A study of a water-catching machine from air using an AC cooling system working on a vapor compression cycle consisting of a compressor with a power of 1.5 PK and refrigerant R-22 with a fan speed of 400 rpm and 450 rpm was conducted[2]. The fan rotation speed used was 450 rpm, and the highest COP of 4.7 was attained. The ideal COP value at 450 rpm was 5.61. The greatest efficiency obtained was 84.42%. Nevertheless, the cold air coming out of the engine was discharged into the environment or was not used for other purposes.

An investigation on a machine that produces water from air using an AC cooling system that worked with a vapor compression cycle consisting of a 1.5 PK compressor, a condenser, a capillary tube, and an evaporator was also performed[3]. The modification applied in the study was the addition of 2 fans in the condenser (one fan in front of the condenser and another fan behind the condenser) and one fan in front of the evaporator as an air compressor. The results showed that the actual COP found was 4.75 at a fan rotation speed of 350 rpm. The efficiency of 85.8% was gained at 350 rpm fan rotation. However, again, the cold air was not used.

Another researcher[4] conducted research on water-catching machines from the air using an AC engine component of 1.5 PK where the results of the research were the highest actual COP of 4.77 at 250 rpm. The highest efficiency value that could be achieved was 85.63%, and the water production was 4280 ml/h. However, the study also did not take advantage of the cold air that came out of the engine.

Recently a researcher[5] conducted a study on the effect of the position of the evaporator on the amount of dew water produced. The differences in the position of the evaporator were vertical, 45º, and horizontal. The results showed that the highest amount of water of 0.3537 kg was produced by the evaporator in the vertical position. Meanwhile, at the 45º evaporator position, the water obtained was 0.2511 kg, and the lowest water production of 0.1212 kg was attained in the horizontal evaporator position. The highest COP of 9.9 was found for the vertical evaporator position. In this study, the cold air was not used either.

Similarly, a study[6] had been conducted to determine the effect of the number of vertical evaporator pipes on the mass flow rate of water condensed from the air. However, the study did not investigate the cold air that came out of the engine. The machine was operated using refrigerant R134a with a compressor power of 0.5 PK. The study employed evaporator pipes of 25, 50 and 75. The results showed that the 75-pipe evaporator produced water 0.5043 kg.

A research on the effect of the number of evaporators on water production of an air-water harvester was conducted[7]. Water was produced on the walls of the evaporator in convection and free condensation heat transfer modes. The dimensions of the evaporator are 480 mm × 285 mm × 6.25 mm, and were made of copper tubing. Evaporators were installed in parallel in an open box (top and bottom open) with a size of 500 mm × 500 mm × 500 mm. Refrigerant R134a was used as the 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 flowed naturally and some of the moisture in the air condensed. Three variations of the evaporator were tested in case A (one evaporator), case B (two evaporators), and case C (three evaporators). Each evaporator contained 25 copper pipes and the length of each pipe was 285 mm. Maximum water production and evaporator efficiency achieved were 0.51 liter a day and 13% respectively. The engine COP ranged from 5.2 to 13.3. Increasing the number of evaporators could increase water production. Nevertheless the cold air was also not utilized for other purposes.

Based on the paragraph above, the cold air coming out of the dew-generating machine has not been utilized and there has been no research on this. The researchers in the paragraphs above just throw cold air into the environment. For this reason, this study tried to examine the ability of water-producing machines to cool drinking water. So the study was to make a prototype of an air-water harvester and used to cool the drinking water. An air-water harvester or air-water generator (AWG) was a device that condensed water vapor in the air and collected it. Air from outside the machine was sucked into the condensation chamber and then condensed into water. The mass of the drinking water was varied with the aim of knowing the machine's ability to cool the drinking water. The indicator of the machine's capability was dE/dt. If dE/dt was less than zero, then the machine was adequate to cold the drinking water. The upper part of the machine was the dew-producing chamber, which contained the evaporator, fan, and dew container, while the lower part of the machine was the beverage cooler chamber, where cold air leaving the condensing chamber was passed through the chamberso that the expected beverage temperature was below 25°C.

II. Material And Methods

The method used in this study was experimental method using an experimental apparatus shown in figure 1. The apparatus contains a condenser, an evaporator, a compressor, an expansion valve (capillary tube), a condensing unit and a cooling chamber. Dependent variables were variables that could not be adjusted, and their values were obtained at the time of data collection and included in data analysis. The variables included were mass of condensed water, the temperature of the air entering the beverage cooler, drink temperature, the temperature of the air coming out of the machine, and COP. 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 0 kg without drinking water, 1.5 kg of drinking water, and 3 kg of drinking water. All the temperatures were measured using K-type thermocouples, while the pressures were measured using pressure gauges. The mass of the drinking water measured using a digital balancer.

In Figures 1, the apparatus consist of two chambers, namely the condensing chamber(A) which has an evaporator and the beverage chamber(B) where the drinking water is cooled. However, it should be emphasized here, that the tool used is a water-producing device or called an air-water harvester, neither a refrigerator nor air conditioner. If the mind is focused on the refrigerator, it will be carried in the wrong direction which is different from the context of this study. The striking difference between the air-water harvester and the refrigerator machine is that the air-water harvester has air circulation in and out, while the refrigerator machine does not. Then this machine is not set at a low temperature because it does not aim to freeze water or goods as in the upper refrigerator or freezer, but is set at a temperature below the dew point temperature slightly so that the process of condensation of water vapor in the air occurs.

Air enters through the top fan, and then enters the condensation chamber. Some of the water vapor in the air condenses in the condensation chamber and the moisture is collected in a water bath. After the condensation process occurs, the air leaves the condensation chamber and enters the drinking water chamber. This air is still cold so it is expected to be able to cool drinking water at temperatures below 25°C and in negative *dE/dt* heat.

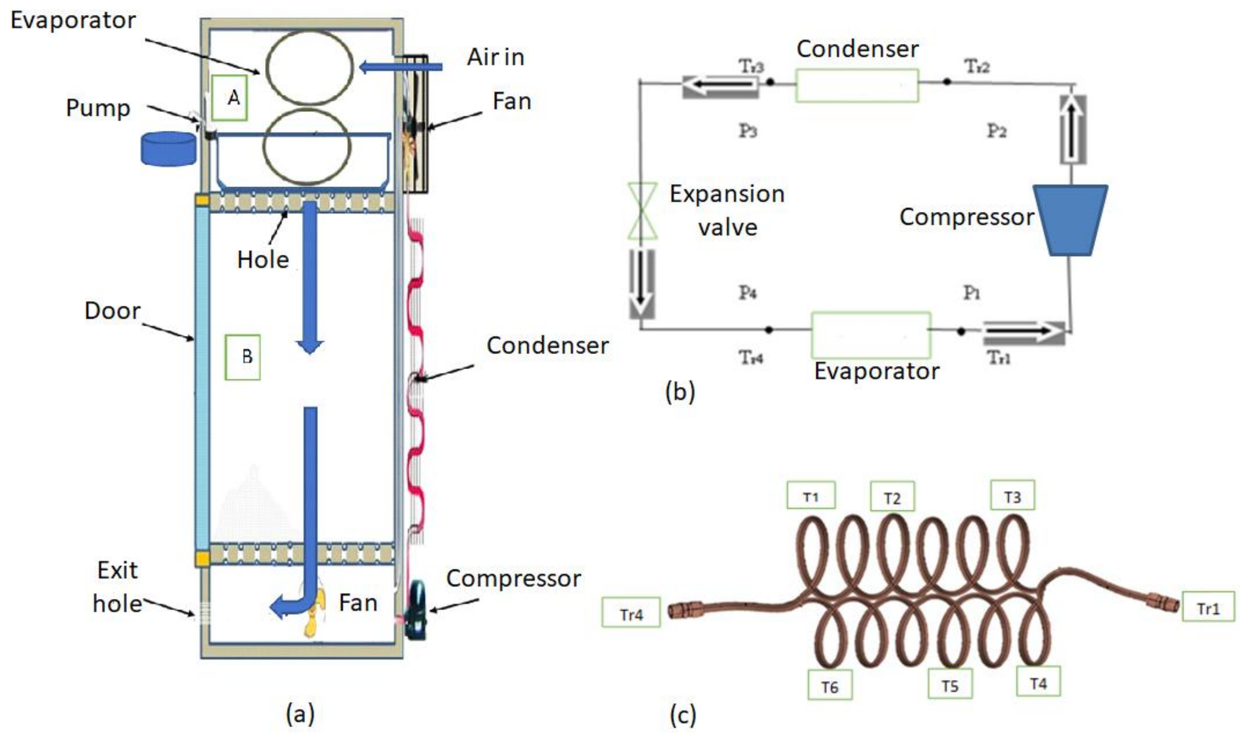

Figure 1. The experimental apparatus; (a) a complete unit, (b) refrigerant circuit, (c) evaporator shape

After going through the drinking water chamber, air flows to the outside through the holes at the bottom with the help of a fan. There are two fans, one on the top and the other on the bottom, so that the air flow is smooth. If only one fan is at the above or below, the air flow is obstructed.

The selected evaporator is in the form of a coil and is placed horizontally in the condensation chamber (A). Besides that, there has been no research on the effect of the shape of the evaporator on the amount of water produced and there has also been no research on the position of the coil-shaped evaporator. What already exists is a study of the position of the evaporator on the mass of water produced, but the evaporator is in the form of parallel pipes. Researchers found that it was the vertical position that produced the most water (vertical pipe evaporator). In this study, a vertical position was chosen because the condensation space (A) was not sufficient if the evaporator was arranged vertically. Then the condenser was not installed with a fan to facilitate heat transfer, because even without a fan the condenser was able to condense the refrigerant from vapor to liquid completely. Therefore, if the fan was attached to the condenser, it only increased the consumption of the electric power.

So the focus of this research is on the drinking chamber (B) only, while the COP and condensed water are only additional results from the study. The temperature and RH of air entering the chamber (B) was indicated by T_{out}, RH_{out}, and the temperature and RH of air leaving the chamber (B) was indicated by T_{out1}, RH_{out1}.

III. Result

The test results are processed and displayed in the form of graphs to make it easier to analyze the data. The COP of the machine should be the same for all variations, because the COP was not affected by the mass of the drinking water, because the condensation process occurred in the condensation chamber, which was before the air entered the drinking water chamber, see Figure 2. This research actually only utilized cold air that came out of the condensation chamber. So that the mass of the drinking water that was put in the drinking water chamber did not affect the condensation process, or it should not affect the COP of the machine. So at all the mass of the drinking water should not affect the COP. But in fact in this study the results showed differences. This was most likely due to the unstable evaporator pressure at 40 psi which caused the refrigerant temperature to also fluctuate resulting in different enthalpies. Different enthalpies produced different Q_{in} and W_{in}, consequently the COP was different.

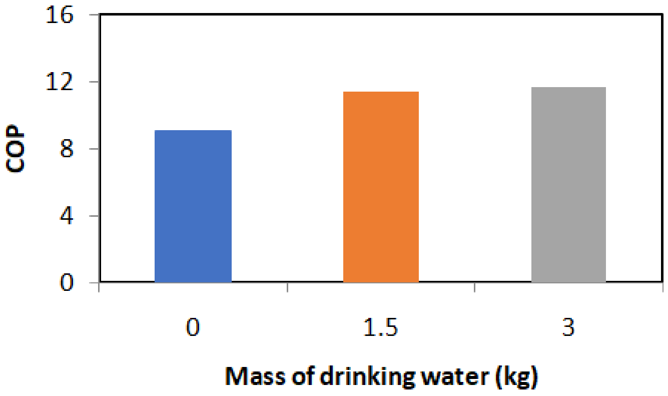

Figure 2. COP of the system

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The highest average air temperature can be seen in the 3 kg water mass of 29.68°C, the 1.5 kg water mass of 28.97°C and the lowest average air temperature, namely the 0 kg water mass of 28.45°C. This is because the temperature of the air coming out the machine increases with the increase in the mass of the drinking water. The more mass of drinking water has the more heat that must be taken up by the flow of cold air. The greater the heat taken, of course, increases the temperature of the air itself at the exit of the air flow. The average temperature of the drinking water chamber (B) in Figure 3 is much higher than 25°C. Therefore, this air-water harvester machine is not ble to cool the drinking waters. The graph showing the average air temperature of the 3 variations can be seen in Figure 3.

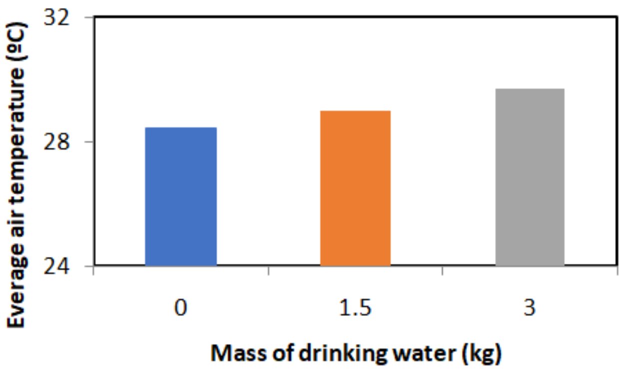

Figure 3. The average air temperatures

The graph showing the average heat of the air passing through the beverage cooler from 3 variations can be seen in Figure 4. Figure 4 shows that the heat of the air is negative because the exit air temperature is greater than the intake air temperature. The heat absorbed by the air from the system (drinking water chamber as a system) at the mass of water 0 kg is -2.68 W (again a negative sign only to indicate that the system is losing heat), then at the mass of water 1.5 kg by -1.95 W and at 3 kg water mass variation of -2.07 W.

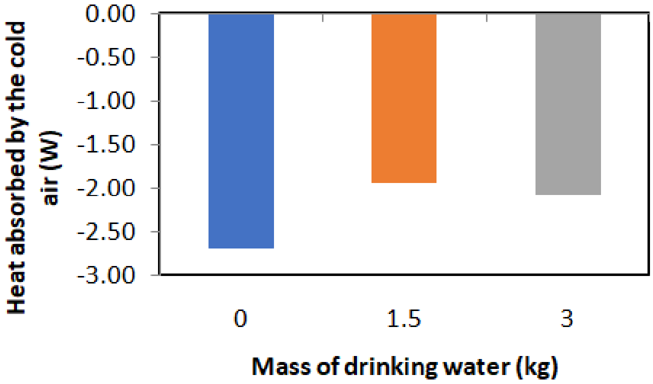

Figure 4. Heat absorbed by the cold air flowing inside the drinking water chamber

Figure 5 shows negative *dE/dt* only for zero kg or empty drinking water chamber, this means that the air-water harvester machine is only able to cool empty chamber, while for the chamber filled with drinking water, the machine is not capable. This machine's capability assessment is based on the heat absorbed or released from the drinking water and beverage space. If *dE/dt* is positive, the heat in the chamber and in the drinking water cannot be completely taken up by the flow of cold air coming out of the condensing chamber. Figure 5 shows the power that can cool drinking water at a drinking water mass of 0 kg of negative 0.20 W, meaning that the air is able to cool an empty chamber system (without being filled with drinking water). Then the power to cool the drinking water at a mass of 1.5 kg is positive 0.44 W (this positive indicates the device is not able to cool the system) and the power to cool a drinking water at a mass of 3 kg is positive 0 .74 W too (this also indicates the machine is not able to cool the system). From Figure 5, a partial conclusion can be made, namely that the cold air coming out of the condensation chamber is not able to cool the system filled with drinking water, because the *dE/dt* is a positive.

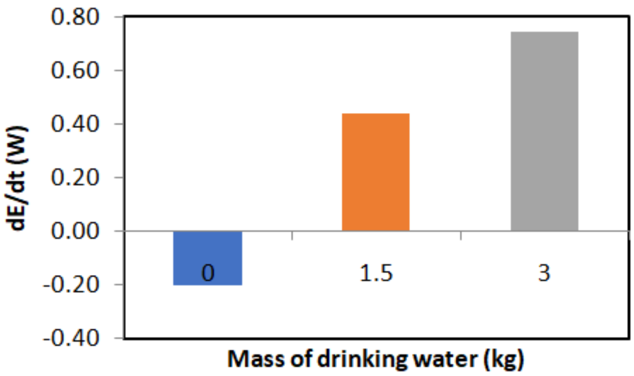

Figure 5. Power to cool drinking water

Thermodynamically *dE/dt* that can be taken from a book[8] is expressed by:

$$\dot{Q} - \dot{W} - \sum \dot{m}_e h_e + \sum \dot{m}_i h_i = \frac{dE}{dt}$$

dE/dt is called the change in energy per unit time in the system (drinking water chamber), not the whole machine system, because this research only focuses on the drink chamber. The COP and the mass of condensed water are only to determine the main performance of the machine as a dew producer or air-water harvester. If *dE/dt* is negative, it means heat is leaving the system (drinking water chamber including the drinking water) by being absorbed by the cold air coming from the condensing chamber and is declared capable of cooling the system, if positive then the machine is said to be unable to cool the system and drinking water.

The graph showing the average water mass obtained from 3 variations can be seen in Figure 6. The resulting water shown in Figure 6 should be the same for all variations, because the water yield has nothing to do with the mass of the cooled drinking water. As explained in the previous paragraph, the condensation process occurred before the air reached the drinking water chamber. Therefore, the mass of the drinking water did not affect the amount of dew mass. Unless the drink water blocked the air flow, then the drinking water definitely affected the results of the condense water. If the air flow was blocked, then the air could not flow normally so that the condensation process was disrupted. The difference in condensation resulted in different masses of drinking water was caused by several factors, including the humidity of the inlet air and the pressure of the evaporator. The humidity of the air entering the engine will determine the amount of dew that is produced. Likewise, the evaporator pressure caused the evaporator temperature to vary. Different evaporator temperatures certainly produced different condensation. However, this study did not analyze the effect of RH on the mass of water produced. Even RH in this case was not included in the analysis because the analyst did not need RH data. Therefore, although RH data were recorded in this study, they were not included in this paper. The recorded RH was only useful for the analysis of heat transfer in the condensation process in the condensation chamber.

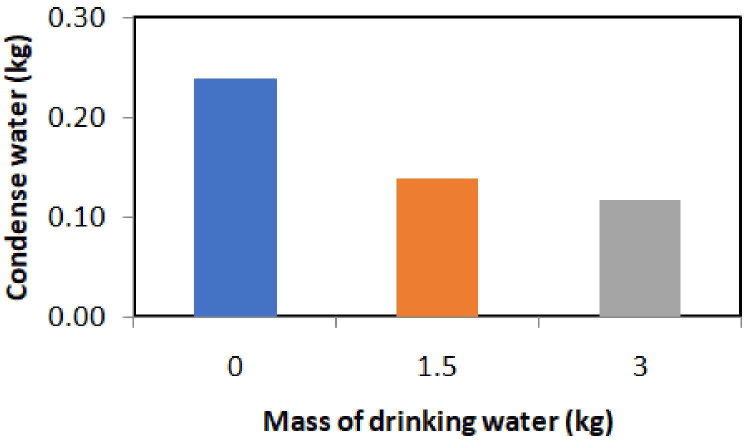

Figure 6. Average water mass yield of 3 variations.

IV. Conclusion

Based on the results of research and discussion on the performance of the air-water harvester machine to cool drinking water, the following conclusions are obtained: the highest COP is 11.67, and the lowest COP is 9.04; the highest average air temperature is 29.63°C and the lowest is 28.45°C; at 0 kg water mass, cold air from the air-water harvester machine is able to absorb heat from the beverage chamber of 2.68 W; the cold air from the machine is only able to cool the empty drink chamber; cold air from the machine is not able to cool the drinking water chamber which contains 1.5 kg and 3 kg drinks; the average drinking water chamber temperature is above 25°C, so the air-water harvester machine is not able to cool the drinks; the highest mass of water produced by the air-water harvester is 0.238 kg and the lowest is 0.117 kg; COP and the mass of water produced from the machine have nothing to do with variations in the mass of the drinking water placed in the drinking water chamber of the air-water harvester machine; the testing and discussion of this study is only focused on whether or not the cold air flowing out of the air-water harvester machine condenser to cool the 1.5 kg and 3 kg drinks.

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