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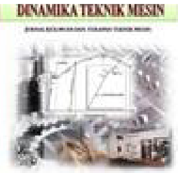

Improving water generator performance by using various evaporator pipe diameters

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ABSTRACT

To overcome the problem of lack of drinking water during the dry season in certain areas, it is necessary to take advantage of technological advances, namely presenting a device to produce water called an air-water generator. However, the capabilities of this machine are still very varied and even very low, therefore it is necessary to conduct further research on this machine. This study aims to determine the influence of evaporator pipe diameter on the mass of water produced. This research was carried out experimentally using a cooling machine with a parallel evaporator made in the laboratory and the working fluid used was R134a refrigerant. The compressor used is a rotary type 0.5 PK compressor. The diameters varied were 1.00 mm, 2.00 mm and 3.00 mm. The results indicated that the highest water mass was 0.330 kg per hour obtained using a pipe diameter of 1.00 mm. Meanwhile, the highest coefficient of performance (COP) was 7.34, obtained at a pipe diameter of 1.00 mm and the highest total heat transfer rate absorbed by the evaporator from the air occurred at a pipe diameter of 1.00 mm, which was 40.4 W.

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1. INTRODUCTION

In the dry season, several areas of Indonesia, including the NTB and NTT regions, frequently suffer from drought conditions. Under these circumstances, local communities often face serious challenges in accessing clean and safe drinking water. To address this issue, the application of technological innovations—such as air-to-water generation devices—has become increasingly important. Despite this potential, the water production capacity of such systems remains highly variable and, in many cases, quite limited. Consequently, further comprehensive investigation into these devices is required. Atmospheric water generators based on cooling or refrigeration principles have been extensively explored in previous studies, including those by Najib (2021), Azari (2022), Faroni (2022), Mirmanto et al. (2021), Hendra (2022), Khatami (2022), Mirmanto et al. (2023, 2024, 2024a), and Mari (2024). Nevertheless, the amount of water produced by these systems is still relatively low, as reported by Mirmanto et al. (2024b).

Azari (2022) experimentally investigated how variations in evaporator tube diameter influence the amount of water produced. The system employed R134a as the working refrigerant in a vapor-compression refrigeration cycle and was equipped with a 0.5 PK rotary compressor. Three evaporator pipe diameters were examined: 10.00 mm, 8.00 mm, and 6.35 mm. The highest water yield, measuring 0.44 kg, was achieved when the evaporator diameter was 8.00 mm. Nevertheless, the relationship between pipe diameter reduction and water

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production did not exhibit a consistent pattern. A decrease from 10.00 mm to 8.00 mm resulted in increased water output, whereas a further reduction to 6.35 mm led to a decline. Consequently, the study was unable to establish a definitive correlation between evaporator diameter and water production. Similarly, the influence of pipe diameter on the coefficient of performance (COP) remained inconclusive, as no clear trend was identified. Although the maximum COP of 11.82 was recorded at an 8.00 mm diameter, along with the highest evaporator heat absorption from ambient air at 74.84 W, these results did not confirm whether COP and heat transfer rate consistently increase or decrease with smaller pipe diameters.

Research consistent with Azari (2022) was later conducted by Faroni (2022). In Faroni's experimental study, the impact of evaporator tube diameter on water output in an atmospheric water harvesting system was analyzed. R134a was used as the working refrigerant, and experiments were performed using tube diameters of 3.00 mm, 4.00 mm, and 6.35 mm. The results demonstrated that evaporator tube size significantly affected both the quantity of water collected and the system's thermal behavior. The highest water yield, amounting to 0.369 kg, was obtained when the smallest tube diameter of 3.00 mm was employed. In addition, this same diameter produced the highest coefficient of performance (COP) of 13.28, as well as the maximum heat absorption from ambient air by the evaporator, which reached 52.101 W. Overall, the results demonstrated that reducing the evaporator tube diameter enhanced water output, system efficiency, and heat transfer characteristics.

The diameter of the evaporator pipe in the water harvester based on Azari (2022) was less clear in its effect on the mass of water production. However, based on Faroni (2022), it can be concluded that the smaller the pipe diameter produces more water mass. Therefore, the author is interested in continuing Faroni (2022) by using even smaller pipes. The variations in pipe diameter used 3.00 mm, 2.00 mm, and 1.00 mm. In this experiment, the heat transfer and condensation processes occur naturally, because this study does not use a fan. Azari (2022) and Faroni (2022) research also used a natural system and would be used as a comparison in the current study. So the purpose of this study is to determine the effect of the evaporator pipe diameter on the performance of the water generator machine (water mass production, COP, COPrev, and total heat transfer).

2. RESEARCH METHODS

The method used in this study was an experiment, namely making a prototype first and then testing it with the independent variable of pipe diameters, namely 3.00 mm, 2.00 mm and 1.00 mm. The evaporator shape was parallel. The pipe diameter was measured using a digital vernier caliper. The environment was not conditioned, the temperature and RH were as they were according to the ambient temperature and RH. However, because the research instrument was placed indoors, there was no very extreme changes in temperature or RH so that throughout the experiment the changed in temperature and RH were not too large. However, the extent of the environmental temperature and RH was still calculated according to what was actually there. This temperature and RH were very necessary, namely to find the portion of water vapor and the enthalpy of the incoming and outgoing air, so that heat transfer from the air to the evaporator walls could be calculated. The image or schematic of the research instrument is presented in Figure 1, consisting of an evaporator, compressor, condenser, expansion valve or capillary tube and dew water container as well as the measuring instruments. The temperature was recorded using a thermocouple connected to an Applent AT45 -24 channel data logger. Pressure was measured using a pressure gauge, while RH was measured using a digital hygrometer. The resulting dew mass was weighed using a Benz BZ-030 digital scale. Compressor power was measured using a digital wattmeter.

The working principle of this device is that when the engine is running, the evaporator cools below the dew point temperature, causing the air touching the evaporator wall to cool and its density to increase. Therefore, this cold air moves downward while the water vapor in the air condenses. As the cold air moves downward, the surrounding air fills the space left by the cooled air, creating a natural flow. All parameters, such as temperature, pressure, and RH, are recorded hourly for 7 hours.

To calculate the COP and heat transfer flow rate the following equations are used. These equations can be seen in Mirmanto et al. (2024a), Cengel and Boles (1994), Fathoni (2022). The mass flow rate of the resulting water can be calculated using equation (1).

$$\dot{m}_d = \frac{m_d}{t} \tag{1}$$

$\dot{m}_d$ is the mass flow rate of water resulting from condensation (kg/s) and m_d is the mass of water weighed directly by using a digital scale. Then w1 and w2 are found using an online psychrometric chart. http://www.hvac-calculator.net/index.php?v=2 based on the temperature and RH of the incoming and outgoing air, and the portion of water vapor that is condensed can be predicted using equation (2).

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

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w_1 is the fraction of water vapor in the air at the inlet side (kg/kg dry air), and w2 is the fraction of water vapor in the air at the outlet side (kg/kg dry air), so that w is the fraction of water vapor that is condensed (kg/kg dry air). The naturally occurring dry air flow rate can be calculated using equation (3).

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

$\dot{m}_{da}$ is the dry air flow rate (kg/s), t is the duration of the experiment (s). Then the inlet steam flow rate can be calculated using equation (4).

$$\dot{m}_v = w_1 \dot{m}_{da} \tag{4}$$

$\dot{m}_v$ is the rate of incoming water vapor flow (kg/s). The rate of heat transfer from the dew flow can be calculated using equation (5).

$$\dot{q}_d = \dot{m}_d h_{fg} \tag{5}$$

$\dot{q}_d$ is the heat flow rate of the condensed water vapor (W), and hfg is the enthalpy of evaporation or condensation (kJ/kg) which is found from the saturation vapor table based on the average temperature of the inlet and outlet air. The heat flow rate of the dry air is calculated using (6).

$$\dot{q}_{da} = \dot{m}_{da} c_p (T_{in} - T_{out}) \tag{6}$$

$\dot{q}_{da}$ is the heat flow rate of dry air (W), cp is the specific heat of air (J/kgK), Tin and Tout are the inlet and outlet air temperatures (°C). The heat transfer rate of cooled but uncondensed water vapor is predicted by equation (7).

$$\dot{q}_v = \dot{m}_v c_{pv} (T_{in} - T_{out}) \tag{7}$$

$\dot{q}_v$ is the rate of heat transfer from non-condensable water vapor (W), cpv is the specific heat of steam (J/kg°C). So the total heat transfer from the air to the evaporator wall is calculated using equation (8).

$$\dot{q}_t = \dot{q}_d + \dot{q}_{da} + \dot{q}_v \tag{8}$$

COP can be found using equation (9). h_1, h_2, and h_4 are the enthalpies of the refrigerant entering and leaving the compressor and exiting the capillary tube (J/kg). All enthalpies are found based on temperature or pressure or temperature and pressure depending on the condition of the refrigerant. If the condition is saturated, it can be found using temperature or pressure alone, whereas if the condition is superheated, the enthalpy is found using temperature and pressure.

$$COP = \frac{h_1 - h_4}{h_2 - h_1} \tag{9}$$

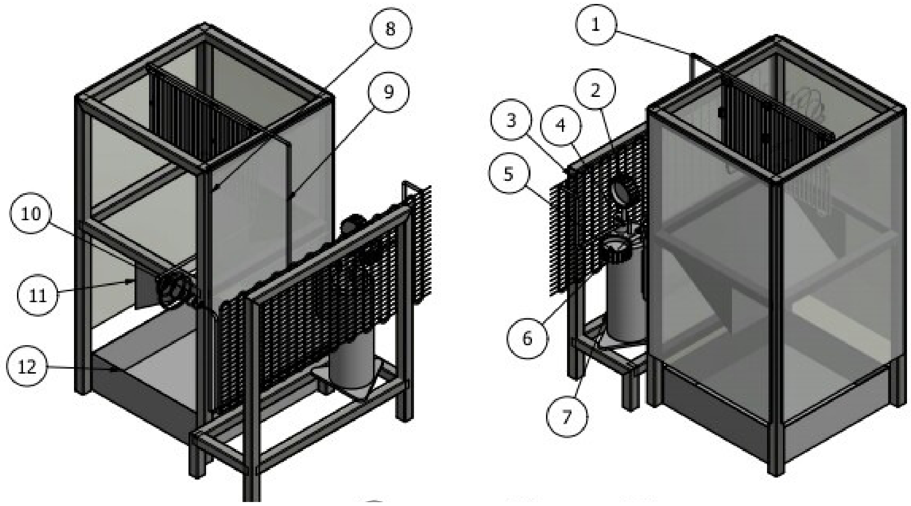

Figure 1. Natural convection water harvester water machine apparatus. (1) evaporator, (2) compressor outlet pressure gauge, (3) condenser, (4) compressor outlet pipe, (5) compressor inlet pressure gauge, (6) compressor inlet pipe, (7) compressor, (8) insulated wall, (9) pipe to compressor inlet, (10) capillary tube, (11) dew draining place, (12) dew water collection tank.

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3. RESULTS AND DISCUSSION

The experimental results were obtained to evaluate the influence of evaporator pipe diameter on the amount of water condensed from air under natural convection conditions. The collected data were subsequently processed and presented in graphical form to facilitate interpretation. A similar analytical approach has been adopted in earlier studies, including those by Mirmanto et al. (2014), Ardiansyah (2025), and Amrillah (2025).

Figure 2 presents the mean mass of water obtained from three diameter variations over a three-day testing period. As illustrated in Figure 2, the evaporator pipe with a diameter of 1.00 mm yielded the highest average water mass at 0.308 kg, followed by the 2.00 mm pipe at 0.261 kg, and the 3.00 mm pipe at 0.243 kg. These results indicate that reducing the evaporator pipe diameter leads to an increase in water production. This behavior can be attributed to the smaller condensation contact area on the inner wall of the 1.00 mm pipe, which promotes easier droplet detachment and dripping compared to larger diameters. As a result, a greater quantity of condensate is collected when using the smallest pipe diameter. This observation is consistent with findings reported in Fathoni (2022), which showed that smaller pipe diameters are associated with higher heat transfer rates.

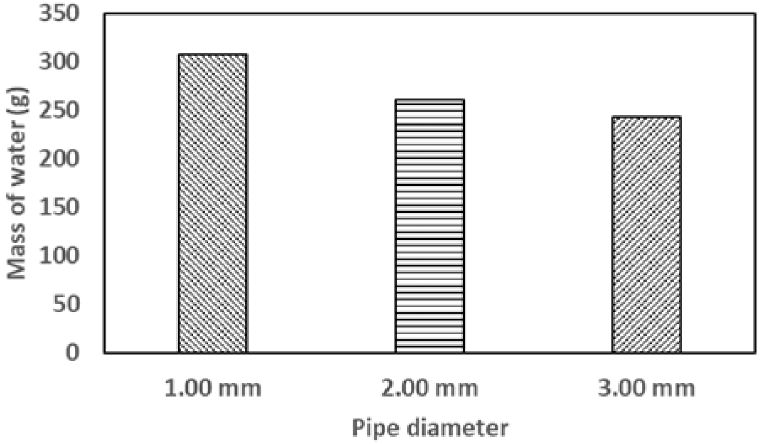

Figure 2. Mass of water produced versus pipe diameter.

The coefficient of performance (COP) is defined as the ratio between the heat absorbed by the refrigerant in the evaporator and the work input to the compressor. As shown in Figure 3, the highest COP value of 6.93 was obtained using an evaporator pipe diameter of 1.00 mm. For pipe diameters of 2.00 mm and 3.00 mm, the COP values were 5.42 and 6.01, respectively. These variations are partly affected by ambient temperature conditions. Higher surrounding temperatures allow the system to absorb more heat, which in turn leads to an increase in COP. In this study, the ambient temperatures during the tests with 1.00 mm and 3.00 mm pipe diameters were slightly higher than those recorded during the 2.00 mm experiment. This difference arises because the test room was not temperature-controlled and was directly influenced by environmental conditions. As greater heat absorption generally results in higher COP values, the observed results suggest that the influence of evaporator pipe diameter on COP cannot be clearly distinguished. Both COP and COPrev decreased when the diameter was reduced from 1.00 mm to 2.00 mm, but increased again at 3.00 mm, indicating the absence of a consistent increasing or decreasing trend with respect to pipe diameter. To clarify this behavior, further experiments using smaller diameters, such as 0.50 mm, are recommended. If a higher COP is observed at 0.50 mm, it may suggest the presence of an anomaly at the 2.00 mm diameter.

The final variable which is one of the performances of the air water harvester machine is the total heat transfer from the air into the evaporator which can be calculated using equation (8). Figure 4 shows the total heat transfer rate calculated using experimental data.

Figure 4 demonstrates the same phenomenon with COP. COP does not show an increasing or decreasing trend with increasing pipe diameter. However, Figures 3 and 4 show a difference: the COP in the 3.00 mm pipe is actually the highest, while in Figure 4, the highest total heat transfer is found in the 3.00 mm pipe. While there is no trend, however, Mirmanto (2024b) showed higher heat transfer in the smallest channels. The reason for this is that as the channel becomes smaller, all water molecules come into direct contact with the heat transfer wall, maximizing heat transfer. Conversely, in larger pipes, the most fluid molecules is far from the heat transfer wall, thus reducing heat absorption.

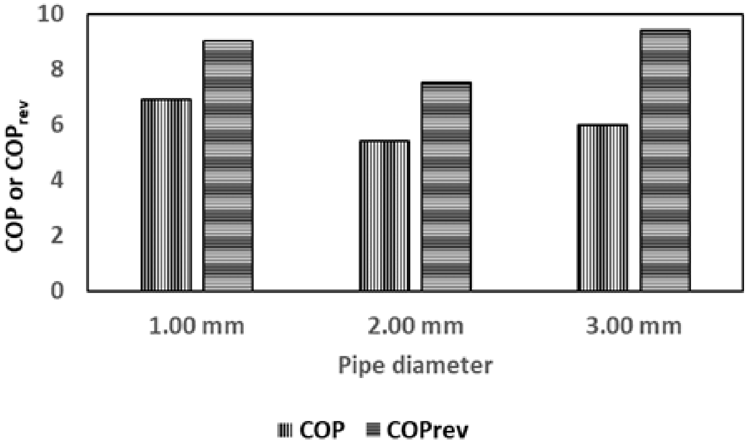

Figure 3. COP and COPrev.

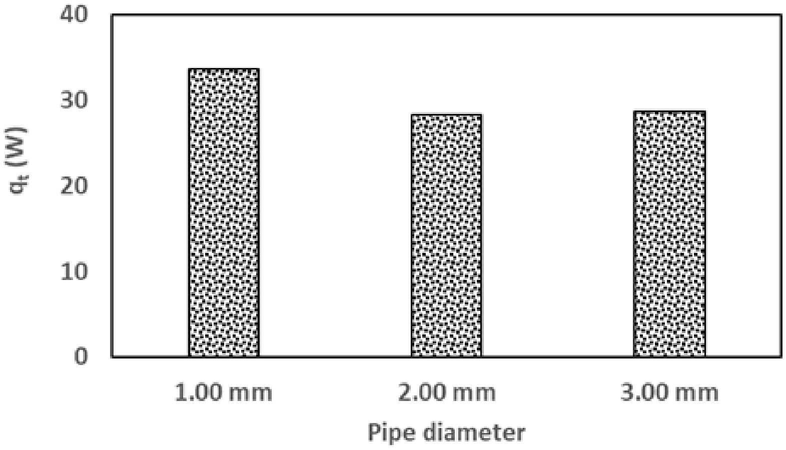

Figure 4. Total heat transfer from the air to the evaporator wall.

As stated in the introduction, the results of this experiment will be compared with the research results of Azhari (2022) and Faroni (2022), which both used a natural convection system and a parallel pipe arrangement for the evaporator. Faroni (2022) concluded the highest water mass of 369 grams obtained from the 3.00 mm pipe, while Azhari obtained 440 grams from the 8.00 mm pipe. From the comparison, it appears that the higher the diameter, the greater the mass of water production. However, this conclusion cannot be used because the three studies with different diameters were carried out by different operators and conditions were also different considering that their experiments were carried out in unconditioned rooms. Meanwhile, what Faroni (2022) did showed that the smaller the pipe diameter, the greater the mass of water production and its heat transfer rate. Meanwhile, Azhari (2022) has not been able to conclude the results because the largest mass of water was obtained at a diameter of 8.00 mm while the pipe diameters tested were 6.35 mm, 8.00 mm and 10.00 mm. So, the effect of the diameter of the evaporator pipe of the water generator machine needs to be re-examined more accurately, under the same conditions and the same operator.

4. CONCLUSION

Based on the study examining the influence of evaporator pipe diameter on water mass production, COP, COPrev, and total heat transfer in an air–water generator, it can be concluded that reducing the pipe diameter increases the amount of water produced. The highest water yield of 0.308 kg was achieved using a 1.00 mm diameter pipe, which also resulted in the maximum COP of 6.93 and the greatest heat absorption from ambient air at 33.67 W. Consequently, an evaporator pipe diameter of 1.00 mm is recommended when water production is considered the main performance criterion. While the trend for water mass production is clearly correlated with decreasing pipe diameter, no consistent pattern was observed for COP, COPrev_{rev}rev, or total heat transfer with changes in evaporator diameter.

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