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EFFECT OF EVAPORATOR DIAMETERS ON PERFORMANCES OF A CUSTOM AIR WATER GENERATOR

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ABSTRACT

A study to examine the effect of evaporator diameters on the performances of a custom air-water generator had been conducted in naturally room air temperatures. Performances in this study consisted of fresh water production, coefficient of performance, and total heat transfer from the air. The freshwater was attained from the dew that dropped from the evaporator walls. It was from water vapour in the air that condensed due to the low temperature of the evaporator walls. The evaporator which had dimensions of 285 mm x 12.7 mm x 480 mm was placed in an open box (top and bottom). It was made of copper pipes. There were three evaporators tested with different diameters. Case A indicated the diameter of the evaporator was 3.00 mm, Case B was the evaporator with a diameter of 4.00 mm, and Case C was the evaporator with a diameter of 6.35 mm. The results showed that the maximum fresh water obtained was 0.369 kg, the coefficient of performances found ranged from 7.8 to 18.6, and the highest total heat transfer was 152.1 W.

Keywords: *Air water generator, fresh water, coefficient of performance, total heat transfer.*

1. INTRODUCTION

Regions in Indonesia that were frequently issued to drought during the dry season were NTT, Central Lombok, and several parts of East Java. People may consume unclean murky water, which is not recommended for health. Meanwhile, there were some techniques to attain clean water, e.g. sanitizing muddy water, seawater distillation, reverse osmosis, dew harvesting net, foil material dew harvesting and windmill dew harvesting, Mirmanto et al. (2021, 2022a, 2022b).

Purifying dirty water, as reported by Yang et al. (2010) and Fitrahani et al. (2012), needs much energy and the clean water result is less. Therefore, this method is not satisfied to fulfil the water demand, unless it is operated using alternative energy. The seawater distillation method that had been investigated by previous researchers, e.g. Panchal et al. (2015), and Mirmanto et al. (2019) was the cheapest way to obtain clean water; however, it was not suitable for people who lived far from the beaches. The most powerful method to attain fresh water was reverse osmosis as it had been investigated and studied by researchers, e.g. Ibrahim et al. (2020). Nevertheless, this method needed a lot of energy due to the high pressure required. A device to harvest water from the air without energy was dew harvesting nets that had been studied previously by Harb et al. (2016) and Jarimi et al. (2020). However, this device could not work optimally in a dry area where the fog was not available. Previously, a method had been discovered. This method used foil materials to capture the vapour in the air at the night, Maestre-Valero et al. (2011) and Nelson et al. (1994). It used solar energy to evaporate the condensed vapour trapped in the foil materials and then the evaporated vapour was condensed in the box and collected. Unfortunately, this method had low freshwater production. Some studies exposed a method to extract water from the air using windmills as reported by Tu et al. (2018) and Wang et al. (2019). The method could produce large freshwater; however, it was not suitable for people with a low income, because it was not cheap. Recently, there was an inexpensive method. It could be used for households as long as electrical power was available. This method was also simple, durable, and easy to maintain. However, the production of water depended on the amount of electrical power. The method was examined by several researchers, e.g. Mirmanto et al. (2021, 2022a, 2022b).

Using refrigeration machines to capture water vapour in the air was applicable in all locations and conditions. However, the larger machine required higher electrical power, consequently, higher cost. Nevertheless, electrical power could be obtained from renewable energy such as solar panels in the future. The problem with the method was freshwater production. It could not produce much freshwater due to some parameters such as relative humidity, temperature, construction of the evaporator, and the heat transfer area of the evaporator.

In this study, the parameters investigated were the evaporator diameters due to some previous researchers. Previous studies elucidated that decreasing the size of the pipe diameter increased the heat transfer rates, e.g. Venkatesan et al. (2010), Wang and Sefiane (2012), and Mirmanto (2014). Based on those studies, decreasing pipe diameter might increase the amount of fresh water. Therefore, the study investigated the effect of evaporator diameters on the performance of the air-water generator.

2. MATERIALS AND METHOD

Fig. 1 confirms the experimental equipment that was used in this study. The apparatus consisted of a condensation unit (evaporator), a capillary tube, a compressor, a condenser, and a box. The condensation unit was formed through copper tubes orderly in parallel. Note that in this study, the evaporator is called a condensation unit. Case A was a condensation unit with a pipe diameter of 3.00 mm, Case B was with a pipe diameter of 4.00 mm, and Case C was with a pipe diameter of 6.35 mm. The three condensation units had the same heat transfer area, and then the number of pipes in each condensation unit was different. Case A had 53 pipes, Case B had 40 pipes and Case C had 25 pipes. The thermocouple dispositions are plotted in Fig. 2. The device used a

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friendly refrigerant (R134a) at 40 psi of low pressure and 180 psi of high pressure. The electrical power ranging from 197 to 204 W was applied.

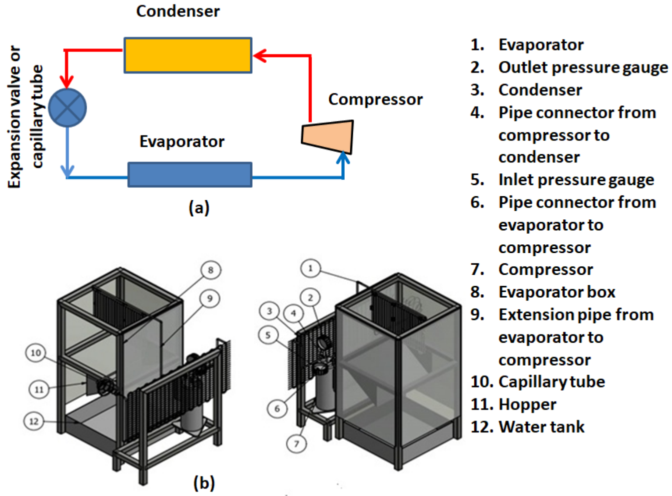

Fig. 1 Experimental apparatus and schematic diagram of the vapour cycle.

K-type thermocouples were applied to record all temperatures. The thermocouples were connected straight to the cDAQmx 9714 NI data logger. They were standardized in an oil bath with a heater connected to a PID. The calibration process gave an uncertainty of ± 0.5°C. The air temperatures at the entrance and the exit were noted and the inlet and outlet air relative humidity (RH) were also recorded. The water condensed was evaluated with a digital weighing scale having an uncertainty of ± 1 g. The electrical power of the device was monitored by a digital-watt meter.

Many factors influence the amount of freshwater production, e.g. surrounding air temperature, RH, the evaporator geometry and compressor power. The parallel geometry study was ever conducted by Mirmanto et al. (2022a, 2022b) with a pipe diameter of 6.35 mm. Therefore, on this occasion, the diameters of the condensation unit were studied. The air-water generator (AWG) worked efficiently when the air temperature was low and RH was high. As a criterion, the AWG did not work effectively when the RH dropped below 30%. To minimize the effect of RH and temperatures, the device was placed in a room with RH and temperatures were from 76% to 82% and 27.7ºC to 31ºC.

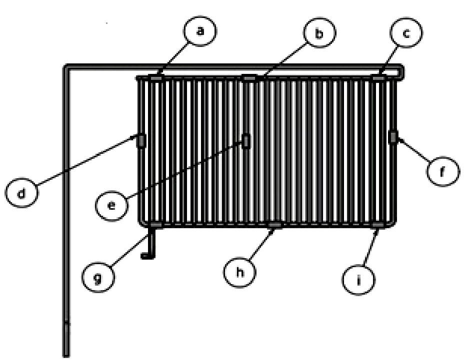

Fig. 2 Placements of thermocouples on the condensation unit walls, a to i.

The amount of heat energy absorbed by the refrigerant in the condensation unit can be estimated using Eq.(1), which is called cooling capacity and it can be obtained in the book written by Cengel and Boles (1994) and also was used by Mirmanto et al. (2021, 2022a, 2022b). The equation refers to the vapour cycle revealed in Fig. 3.

$$Q_{in} = h_1 - h_4 \tag{1}$$

Q_{in} is the heat energy absorbed by the refrigerant in the condensation unit (J/kg), and h_1 and h_2 are the enthalpies in States 1 and 2, correspondingly. In State 4 the energy per unit mass is supposed to be the same as in State 3. This assumption was due to the theory written in the book of Cengel and Boles (1994). In addition, Q_{out} is the heat energy disconnected from the refrigerant in the condenser unit. In this unit, the refrigerant changes its form from vapour to saturated liquid at high temperatures and pressure. This energy is written as

$$Q_{out} = h_2 - h_3 \tag{2}$$

h_3 is the enthalpy at the State 3. Another parameter that is important to know in this study is the work of the compressor, W_{in} (J/kg), which is formulated as

$$W_{in} = h_2 - h_1 \tag{3}$$

$$COP = \frac{Q_{in}}{W_{in}} \tag{4}$$

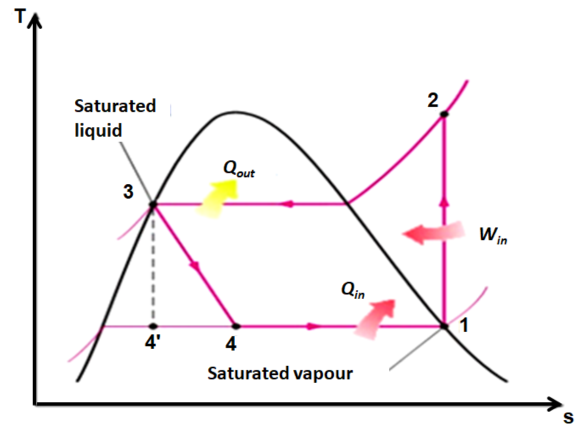

Fig. 3 An ideal T-s vapour cycle of refrigeration.

A digital watt meter with capacity measurements of 0–100 A and 80–260 V was used to evaluate the electrical power consumed by the compressor. It is written as

$$P_c = VIP_F \tag{5}$$

V indicates a voltage (V), I represents a current (A), P_c denotes the electrical power (W), and P_F is the power factor. The electrical power formulation was also utilized by Mirmanto et al. (2021, 2022a, 2022b). The refrigerant mass current, $\dot{m}_{ref}$ (kg/s), can be approximated by applying Eq. (6).

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

Hence, the evaporator and condenser heat transfer rates may be predicted by the equation suggested by Cengel and Boles (1994).

$$\dot{Q}_i = \dot{m}_{ref} Q_{in} \ ; \ \dot{Q}_o = \dot{m}_{ref} Q_{out} \ ; \ \dot{W}_i = \dot{m}_{ref} W_{in} \tag{7}$$

$\dot{Q}_i$ is the hate rate absorbed by the evaporator (W), $\dot{Q}_o$ represents the rate of heat rejected from the refrigerant flowing inside the condenser (W). $\dot{W}_i$ is the refrigerant mass flow rate multiplied by the compressor work (W). The rate of the heat of the air flowing naturally over the condensation unit can be formulated as

$$\dot{Q}_{\text{dry air}} = \dot{m}_{dry} c_p \left(T_{in} - T_{out}\right) \tag{8}$$

$$\dot{Q}_{\text{dew}} = \dot{m}_{dew} h_{fg} \tag{9}$$

$$\dot{Q}_{\text{vapour}} = \dot{m}_{vapour} c_p \left(T_{in} - T_{out}\right) \tag{10}$$

$$\dot{Q}_{\text{t}} = \dot{Q}_{\text{dry air}} + \dot{Q}_{\text{dew}} + \dot{Q}_{\text{vapour}} \tag{11}$$

Equations (8-11) can be seen in Mirmanto et al. (2021, 2022a, 2022b), while equations (8) and (10) can be found in Jaleel and Jaffal (2022), but with different symbols though. $\dot{Q}_{\rm t}$ is the total heat transfer rate from the air absorbed by the condensation unit (W). $\dot{Q}_{\rm dry\ air}$ is the heat rate from the dry air (W). $\dot{Q}_{\rm dew}$ is the heat transfer rate from the freshwater (W) and $\dot{Q}_{\rm vapour}$ represents the heat transfer rate for the water vapour cooled by the condensation unit (W). $\dot{m}_{dry}$ is the rate of the dry air mass flow (kg/s). Due to no fan, the natural convection heat transfer modes occurred in this study. Vapour and dry air mass flow rates were obtained using the temperatures of the dry bulb and RH input to the psychometric chart online, (Free online Psychrometric Calculator, 2023). Meanwhile, the uncertainty analysis formula was engaged by Coleman and Steele (2009). The investigated parameters and uncertainty are given in Table 1.

Table 1 Parameters and uncertainty.

Variable	Range	Uncertainty
Room temperature (T_{am})	27.7 to 31ºC	± 0.5°C
Low pressure (P_l)	35–45 psi	± 1 psi
High pressure (P_h)	160–190 psi	± 1 psi
Mass of dew (g)	293–382 g	± 1 g
COP	7.05–17.69	± 0.2 to 0.8
Ambient RH	76–82%	± 1%

3. RESULTS AND DISCUSSION

Figure 4 reveals the trends of the RH for the three cases. The RH at the outlet increased with time, while the ambient and the inlet RH were almost constant with time. However, the inlet RH was just slightly lower than the ambient RH, this was due to the inlet temperature that was somewhat upper than the room temperature. The higher inlet temperature was due to the condenser location. The inlet thermocouple was located on the wall above the condenser so that the hot air flowed up from the condenser walls to the air inlet. As described in the psychometric chart, increasing the temperature caused a decrease in RH. To eliminate the RH effect, the water production was divided by the RH and it is exposed in Fig. 8. The outlet RH was always higher than the inlet RH. This was because of different temperatures. The temperature at the inlet was higher than the temperature at the outlet. As the RH was also affected by the temperature, then at the lower temperature, the RH was higher. This could be understood from the definition of the RH. RH is the amount of water vapour in the air divided by the maximum amount of water vapour that can be held by the air. At the same amount of water vapour in the air, but different from the maximum amount of water vapour held by the air, the RH can be different. The maximum amount of water vapour held by the air is depended on the temperature. Therefore, in Figure 4, RH_o increases or fluctuates highly because of the decrease in outlet temperatures.

In this study, parameters, e.g. W_{in}, Q_{in}, *COP*, $\dot{Q}_{\rm t}$ are studied. The energy of cooling can be predicted by Eq. (1), and the calculated W_{in}, Q_{in}, and *COP*, are given in Fig. 5. The data of Q_i that was almost the same for the three cases were roughly constant with time. The phenomena were also found by Mirmanto et al. (2021, 2022a, 2022b). The constant Q_{in} with time indicated that the refrigerant flowing inside the evaporator was stable and also the air temperature was also persistent therefore, there is no increase or decrease in cooling load. In addition, these were also due to the same low-pressure setting at 40 psi for all cases. Meanwhile, the W_{in} was very scattered. This was due to electrical power network fluctuation. The electrical voltage in the laboratory was rather fluctuating because many devices were running. However, on average, they were almost the same. Due to the constant Q_{in} but up and down W_{in}, the *COP* was also up and down too. The *COP* was computed according to Eq. (4). However, the trends of the *COP* were also found by Mirmanto et al. (2021, 2022a, 2022b). The sharp increase in RH_o was due to the outlet air temperatures. Decreasing air temperatures levelled the RH_o, as explained above, and this had been found by Mirmanto et al. (2021, 2022a, 2022b). The outlet air temperatures decreased and then constant with time.

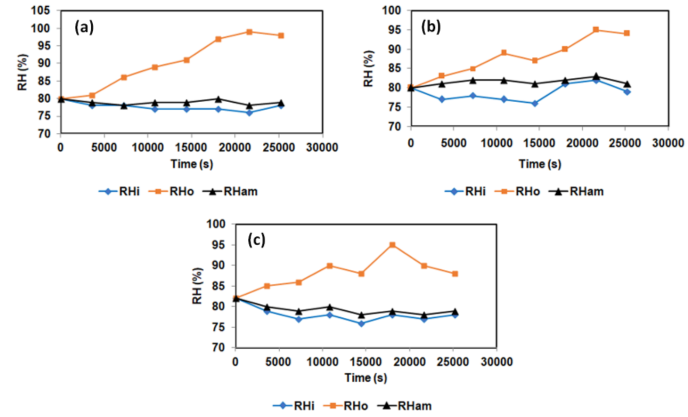

Fig. 4 RH recorded in the experiments for Case A (a), Case B (b) and Case C (c).

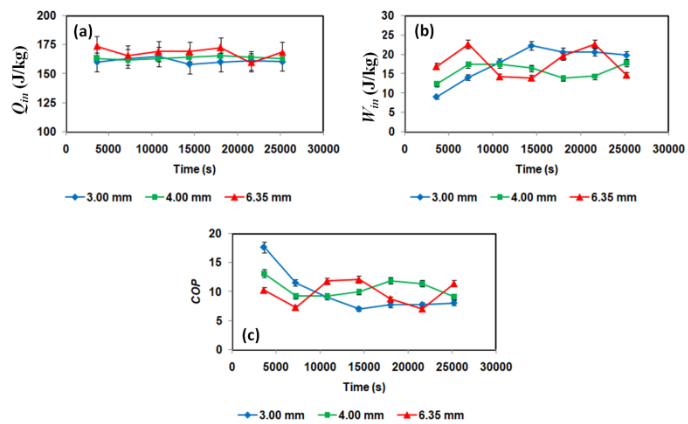

Fig. 5 Parameters investigated in this study for the three Cases.

The effect of condensation unit diameters for the three parameters above was not clear yet, therefore, it should be seen from other parameters, such as total heat from the air, $\dot{Q}_{\rm t}$ and water production. Figure 6 shows $\dot{Q}_{\rm t}$ absorbed by the condensation unit. $\dot{Q}_{\rm t}$ elevated with time for the three cases. The average of $\dot{Q}_{\rm t}$ seems that $\dot{Q}_{\rm t}$ of 3.00 mm diameter (Case A) was higher than others. This agreed with previous studies such as Venkatesan et al. (2010), Wang and Sefiane (2012), and Mirmanto (2014). They stated that decreasing the size of the pipe increased the heat transfer rates. Consequently, $\dot{Q}_{\rm t}$, and freshwater production for Case A was higher.

Figure 7 shows that accumulated fresh water increases with time, and the temporary fresh water is almost constant with time. However, at the diameter of 6.35 mm, the accumulated and temporary freshwater seemed lower than the others. The phenomenon encouraged the statement of Venkatesan et al. (2010), Wang and Sefiane (2012), and Mirmanto (2014). The dew seemed to hold stronger the place when it occurred on the larger area (bigger diameter). Consequently, it could drop when it had big enough weight. On the other hand, dew could not hold the small area; hence, it was easy to drop. When the dew had dropped, then the dew appeared again in the same place. If this phenomenon occurred faster, the collected fresh water was bigger.

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As RH was suspected to influence freshwater production, it should be eliminated. How to eliminate the effect of RH was the freshwater production was divided by RH prevailing in the experiments. Figure 8 shows the relationship of freshwater divided by RH (abbreviated as FW/RH) with time. The trends of FW/RH were the same as the trends of temporary water production. They increased drastically and then were constant with time. FW/RH increased with the decrease in condensation unit diameters.

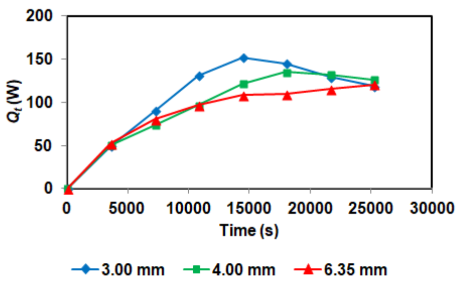

Fig. 6 $\dot{Q}_t$ for three Cases.

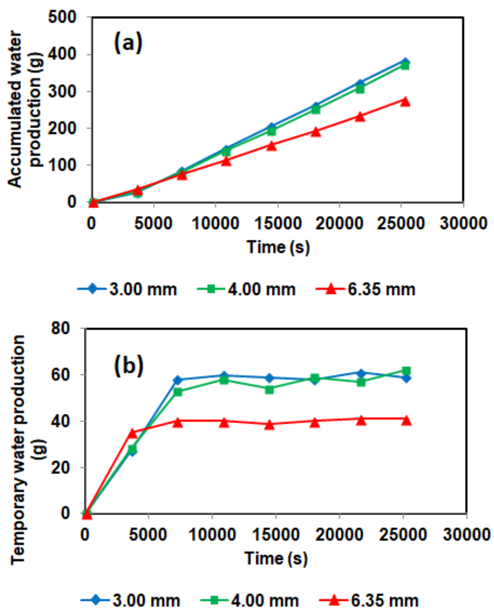

Fig. 7 Accumulated and temporary freshwater production for the three Cases.

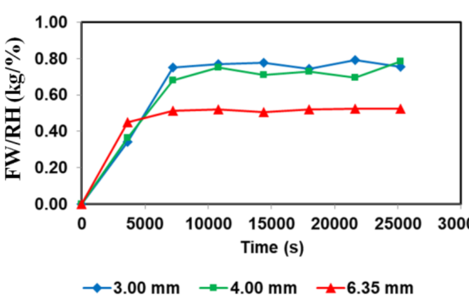

Fig. 8 FW/RH to eliminate the effect of RH on freshwater production for the three Cases.

4. CONCLUSION

An experimental study to observe the effect of diameters on the performance of an air-water generator using a 194-207 (W) refrigeration appliance was performed. Such a study was not investigated previously yet so references were limited. Some investigated parameters indicate that decreasing the diameter increases the performance of the air-water generators. Freshwater production increases with a decrease in diameters, and the total heat transfer rate from the air increases with decreasing the diameters, and the maximum freshwater obtained is 369 g. While for parameters such as COP, Q_{in}, and W_{in}, the effect of diameters is not clear yet. The average COP is 11, and the average Q_{in} and W_{in}, are 164 (J/kg) and 18 (J/kg). It needs a more precise investigation to clarify further effects of the pipe diameter on the performance of the simple air-water generator.

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NOMENCLATURE

AWG	air water generator
a-i	location of thermocouple on the evaporator walls
COP	coefficient of performance
c_p	specific heat (J/kg·K)
h	enthalpy of refrigerant (J/kg)
h_{fg}	enthalpy of evaporation or condensation (J/kg)
I	current (A)
$\dot{m}_{dew}$	mass flow rate of dew (kg/s)
$\dot{m}_{dry}$	mass flow rate of dry air (kg/s)
$\dot{m}_{ref}$	mass flow rate of refrigerant (kg/s)
$\dot{m}_{vapour}$	mass flow rate of vapour (kg/s)
P_c	electrical power (W)
P_F	power factor
Q_{in}	energy absorbed by the refrigerant in the evaporator or condensation unit (J/kg)
Q_{out}	energy rejected by the refrigerant in the condenser (J/kg)
$\dot{Q}_{\text{dry air}}$	heat transfer rate from the air (W)
$\dot{Q}_{\text{dew}}$	heat transfer rate from the dew (W)
$\dot{Q}_i$	heat transfer rate from the evaporator wall to refrigerant (W)
$\dot{Q}_o$	heat transfer rate rejected from the condenser (W)
$\dot{Q}_{\text{vapour}}$	heat transfer rate from the water vapor (W)
RH	relative humidity
s	entropy (J/kg K)
T	temperature (°C)
T_{in}	air temperature at the inlet (°C)
T_{out}	air temperature at the outlet (°C)
V	electrical voltage (V)
W_{in}	compressor work (J/kg)
$\dot{W}_i$	energy per unit time of compressor (W)

Subscripts

1	state 1
2	state 2
3	state 3
4	state 4

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