

Effect of capillary tube length on mass of water production

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ABSTRACT: Water is very important for daily life in use for household needs, agricultural irrigation, plantations, ponds, etc. Various parts of Indonesia lack of clean water in the dry season and this phenomenon occurs every year. Therefore, to overcome these problems, it is necessary to present an advanced technology that can produce water, such as air-water harvester. This technology condenses water vapour in the air using a vapour compression system. This research was conducted to determine the effect of the capillary tube length on water production. The capillary tube lengths tested were 40 cm, 70 cm and 100 cm with a diameter of 0.3 mm. The machine used R134a refrigerant as the working fluid. Based on the results of this study, the recommended capillary pipe length is 70 cm because applying 70 cm capillary tube length, the air-water harvester results in the largest amount of water. It produced water of 1.11067 kg. Meanwhile, using the 40 cm capillary tube length, it produced water of 1.036 kg and utilizing the 100 cm capillary tube length produced water of 0.86233 kg.

KEYWORDS: Air-water harvester, Capillary tube length, Dew water

I. INTRODUCTION

Water is very important for everyday life. Water is used for cooking, bathing and washing in the household. Water is also needed for agricultural irrigation, plantations, ponds, and so on. All sectors of life are highly dependent on the use of water. The territory of Indonesia itself is in the position of a tropical area which has two seasons, namely the rainy season and the dry season. During the rainy season, the need for water is not a problem because the availability of water is easier to meet. On the other hand, in the dry season, lack of water is one of the problems faced by the community for several regions in Indonesia.

Some areas are trying to overcome the difficulty of getting water, especially clean water by sending water aid to drought-stricken areas using water tankers. Not only local governments but also non-government organizations such as institutions or other community groups care about helping areas that are having difficulty to get clean water. In Indonesia, the problem of lack in getting clean water is a problem that always happens itself every year during the dry season. Therefore, to overcome these problems, it is necessary to a tool to produce water.

According to Prasetyo [1], Mirmanto et al. [2], currently there are several methods of catching water from the air, including (a) water catching nets from the air, (b) windmills that catch water from the air, and (c) air conditioning machine. Water catching nets are effectively used in the regions that contain much water vapour (fog). They can produce much water. However, they may be not work when they are placed in the arid areas. Windmills water catcher requires a height and installation location that has a large wind speed to be able to move the mill. It is also an expensive installation and it highly depends on the weather, wind speed, altitude, and wind direction. The air conditioning (AC) machine is one of devices that can be used for catching water from the air. The water vapour condenses on the evaporator walls and the condensed water can be used for fulfilling the water demands. The advantages of using AC are: the components of this machine are easy to obtain, this machine can be operated indoors or outdoors, it can be operated using electricity, batteries, or solar power.

Atmoko [3] conducted a study to make a water-producing device from the air using an AC cooling system with a power of 1.5 PK. The speed rotations were varied 0 rpm, 300 rpm and 350 rpm. The working fluid employed was refrigerant R22. The machine at 350 rpm resulted water of 4.29 l/h which was very large amount of water production.

Nevertheless, in [3], the length of the capillary tube was not mentioned.

Damanik [4] conducted a study entitled of the effect of fan rotation speed on the performance of a water distillation machine from air using a vapour compression cycle. This research used refrigerant R-22 by varying the rotational speed of 2 fans behind the evaporator: 2100 rpm, 2400 rpm and 2600 rpm. The machine resulted water of 2.64 l/h. Again, in this study the capillary tube length was not explained.

Riswoko [5] conducted a research on water harvester machines from air with fan rotation speeds of 400 rpm and 450 rpm and the compressor power used was 1.5 PK. The working fluid used was refrigerant R22. The amount of water produced by the water catching machine at a fan rotation variation of 450 rpm was 4.5 l/h. However, this study did not describe the length of the capillary tube used.

Darmawan and Putra [6], conducted research on air conditioning systems with variations in the length of the capillary tube 35 cm, 65 cm and 95 cm with a diameter of 0.054 in or equal to 1.12 mm with refrigerant R-134a. The results showed that increasing the length of the capillary tube, the cooling capacity, the work of the compressor and the COP decreased. In the shortest capillary tube variation, which was 35 cm, the AC produced a cooling capacity of 2.25 kW, and COP of 5.21. While at the longest capillary tube, the cooling capacity was 0.72 kW, and the COP was 4.35. However, this machine was not for harvesting water from the air.

Recently Mirmanto et al. [2] performed experiments to investigate the effect of evaporator numbers on the water production. They used single, double and triple evaporators. They concluded that increasing the number of evaporators increased the water production. However, they did not observe the effect of capillary tube lengths.

Therefore, since there is an effect of the capillary tube length on the AC performance, as studied by Darmawan and Putra [6], then the capillary tube length may also affect the water production of an air-water harvester. Based on those explanations above, then this study examines the effect of the capillary tube lengths on fresh water production. The lengths of the capillary tube investigated are 40 cm, 70 cm and 100 cm with a diameter of 0.3 mm, and the working fluid is refrigerant R-134a.

II. RESEARCH METHOD AND FACILITIES

To obtain the research aims, the apparatus for performing the study was made and the schematic diagram of the apparatus is presented in Fig. 1. It consisted of an evaporator, a condenser, an air tunnel, a capillary tube, a compressor, fans, thermocouples. The capillary tube lengths tested were 40 cm, 70 cm and 100 cm with a diameter of 0.3 mm. The ambient air came into the condenser to cool it and then the temperature of the ambient air increased, and then the ambient air flowed through the evaporator so that the ambient air temperature decreased drastically. Part of water vapour in the ambient air condensed and flowed into the bucket. The water in the bucket was measured hourly using a digital balance. All temperatures were measured using K-type thermocouples connected to NI data logger NI9714.

The thermocouples were calibrated against a platinum probe thermometer in an oil bath equipped with a PID and a heater to maintain a constant bath temperature. The uncertainty of the temperature was $\pm 0.5^\circ\text{C}$ obtained in the calibration.

The relative humidity was measured using RH meter with resolution of 1% and the properties of the air were attained using an online psychometric chart, <http://www.hvac-calculator.net/index.php?v=2>. The data used as input were dry bulb temperature and relative humidity.

To analysis the experimental data, the following equations are employed:

1. Refrigerant circuit

The machine uses vapour compression cycles; therefore, the theory of the refrigeration machine is used. The process contains isentropic compression from state 1 to 2, heat rejection from state 2 to 3, expansion from state 3 to 4, and heat absorption from state 4 to 1, see Fig. 2. During isentropic compression the compressor work is determined using equation:

$$w_{in} = h_2 - h_1 \quad (1)$$

w_{in} is the work of the compressor (J/kg), h_1 and h_2 are the enthalpy at state 1 and 2. Then the heat rejection process can be described as:

$$q_{ou} = h_2 - h_3 \quad (2)$$

q_{out} is the heat rejected in the condenser to the ambient (J/kg), and h_3 is the enthalpy (J/kg) at state 3. State 3 is saturation liquid. Equations (1) to (2) can be taken from Cengel and Boles [7].

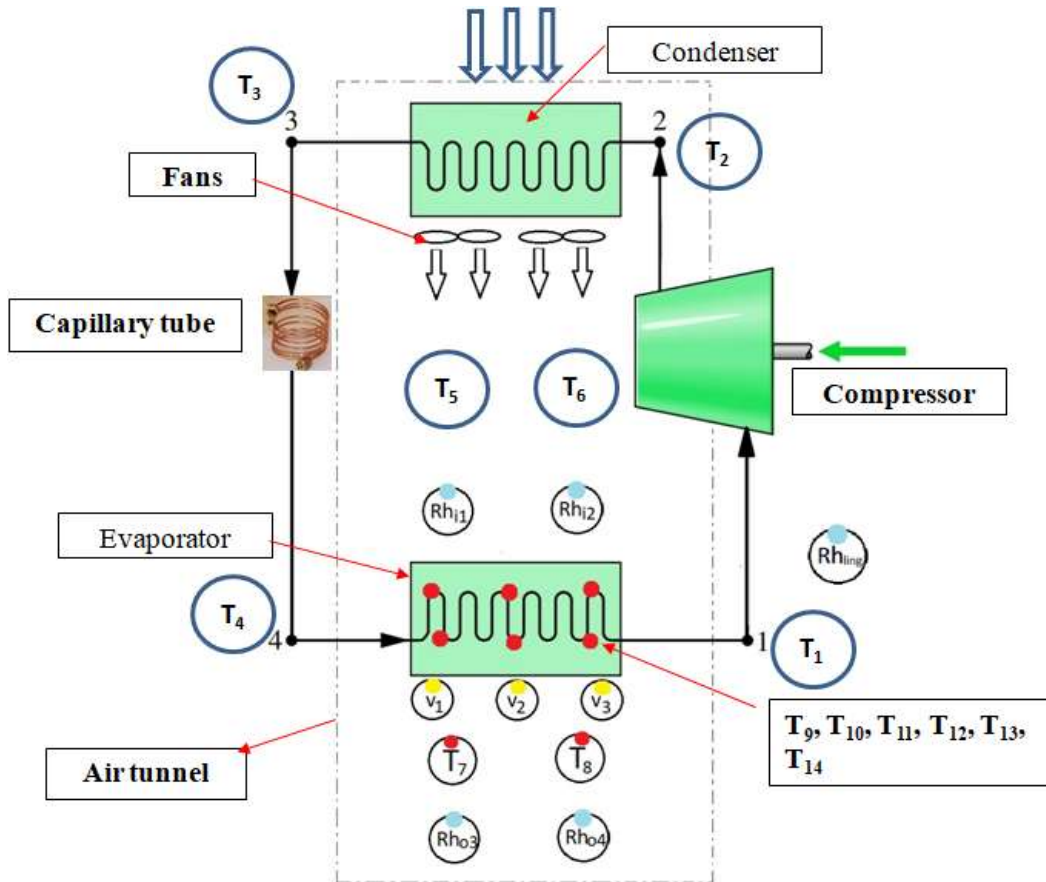


Figure 1. Schematic diagram of the apparatus

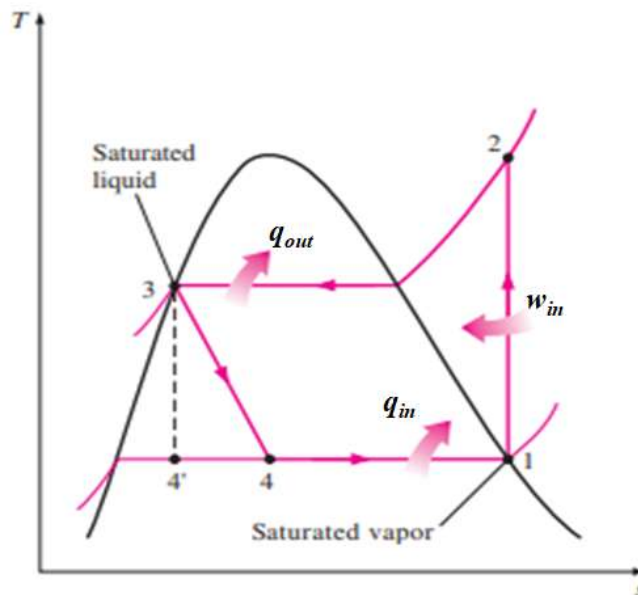


Figure 2. Ideal vapour compression system, Cengel and Boles [7]

Isenthalpic process occurs at the capillary tube, and it is expressed:

$$h_4 = h_3 \quad (3)$$

and the heat absorbed by the machine at the evaporator and it is written

$$q_{in} = h_1 - h_4 \quad (4)$$

q_{in} is the heat absorbed by the evaporator (J/kg).

The performance of the machine can be indicated by COP (coefficient of performance), and it is expressed:

$$COP = \frac{q_{in}}{w_{in}} \quad (5)$$

The value of COP is always bigger than 1. As in this study the mass flow of refrigerant is not measured, and then the circulated refrigerant mass flow rate is determined using an equation below.

$$\dot{m}_{ref} = \frac{P}{w_{in}} = \frac{VIP_F}{w_{in}} \quad (6)$$

P is the electrical power given to the compressor (W), V is the electrical voltage (V), and I is the electrical current (A), and P_F represents the power factor. Then the heat removed by the refrigerant inside the evaporator can be estimated as:

$$\dot{Q}_{in} = \dot{m}_{ref} q_{in} \quad (7)$$

\dot{Q}_{in} represents the heat absorbed by the refrigerant from the inner evaporator wall (W). Equations above can be found in Mirmanto et al. [2, 8].

2. Air side

Heat transfer rate from the air flowing through the evaporator comprises of heat transfer rate from the dry air, heat transfer rate from the water vapour, and the heat transfer rate from the dew (condensed water). The total air mass flow rate, \dot{m}_{air} , can be determined as:

$$\dot{m}_{air} = \rho Av \quad (8)$$

ρ is the density of the air (kg/m^3), A is the air tunnel frontal area (m^2), and v is the air velocity (m/s). Using RH and dry temperature of the air, m_1^* and m_2^* can be obtained from the online psychometric chart. Then the dry air mass flow rate can be estimated as:

$$\dot{m}_{air} = \dot{m}_{dryair} + \dot{m}_v$$

$$\dot{m}_{air} = \dot{m}_{dryair} + m_1^* \dot{m}_{dryair}$$

$$\dot{m}_{dryair} = \frac{\dot{m}_{air}}{1 + m_1^*} \quad (9)$$

m_1^* is the part of water vapour in the air coming into the evaporator (kg/kg_{dryair}), m_2^* is the part of water vapour in the air leaving the evaporator (kg/kg_{dryair}). \dot{m}_{dryair} represents the dry air mass flow rate (kg/s).

$$\dot{m}_v = m_1^* \dot{m}_{dryair} \quad (10)$$

\dot{m}_v is the water vapour mass flow rate (kg/s).

The heat absorbed by the evaporator from the water vapour can be calculated using an equation below:

$$\dot{Q}_v = \dot{m}_v c_{pv} (T_{in} - T_{out}) \quad (11)$$

\dot{Q}_v is the heat from the water vapour (W) that is cooled from T_{in} to T_{out} . T_{in} and T_{out} are the entrance and exit air temperatures ($^{\circ}\text{C}$), and c_{pv} represents the specific heat of the water vapour ($\text{J/kg}^{\circ}\text{C}$). c_{pv} can be obtained from saturated water table. The heat absorbed from the dry air can be estimated as:

$$\dot{Q}_{dryair} = \dot{m}_{dryair} c_{pa} (T_{in} - T_{out}) \quad (12)$$

\dot{Q}_{dryair} is the heat from the dry air (W), c_{pa} is the specific heat of the dry air ($\text{J/kg}^{\circ}\text{C}$), which can be attained in atmospheric air table.

The mass flow rate of condensed water is equal to total mass of condensed water divided by the total time in second, it is written as:

$$\dot{m}_{cw} = \frac{m_{cw}}{t} \quad (13)$$

\dot{m}_{cw} is the mass flow rate of condensed water (kg/s), m_{cw} is the mass of condensed water (kg), and t is total time (s). Then the heat removed from the condensed water can be computed as:

$$\dot{Q}_{cw} = \dot{m}_{cw} h_{fg} \quad (14)$$

\dot{Q}_{cw} represents the heat removed from the condensed water (W), h_{fg} is the heat for evaporation (J/kg). Then now, the total heat removed from the air, \dot{Q}_t is equal to:

$$\dot{Q}_t = \dot{Q}_{dryair} + \dot{Q}_v + \dot{Q}_{cw} \quad (15)$$

The efficiency of the evaporator is then calculated as:

$$\eta_e = \frac{\dot{Q}_t}{\dot{Q}_{in}} \quad (16)$$

All equations above can be seen in Mirmanto et al. [8].

III. RESULTS AND DISCUSSION

The purpose of this study was to determine the effect of the length of the capillary tube on the

amount of water produced from the air. Therefore, there are several stages that need to be analysed either on the refrigerant side or on the air side. The data obtained from the study on the first day with a capillary tube length of 70 cm are shown in table 1. RH_{in} and RH_{out} are the relative humidity at the

entrance and exit of air flow, and are measured in (%). RH_{ling} is the ambient relative humidity (%). P_{low} and P_{high} are pressures in the evaporator and in the condenser respectively. T_4 and T_1 are refrigerant temperatures at the entrance and exit plenums of evaporator.

Table 1. Data taken in the experiment for 700 mm length of capillary tubes for the first day

Time (s)	RHi (%)	RHo (%)	RHling (%)	Mass of condensed water (g)	Air velocity, v (m/s)	Compressor power (W)
0	80	80	80	0.0	0.00	0.00
3600	58.5	57.5	70	112.0	1.73	129.40
7200	58.5	57.5	71	146.0	1.67	128.30
10800	57.5	58.0	78	140.0	1.57	127.30
14400	59.5	59.5	76	155.0	1.67	122.50
18000	60.0	60.5	78	151.0	1.67	121.20
21600	61.5	62.0	73	159.0	1.60	118.40
25200	67.5	69.0	80	170.0	1.70	118.30
Average	62.9	63.0	75.8	147.6	1.66	123.62

Time (s)	P_{low} (Psi)	P_{high} (Psi)	T_{in} (°C)	T_{out} (°C)	T_4 (°C)	T_1 (°C)
0	40	150	27.94	27.84	26.84	26.94
3600	40	150	30.70	29.36	13.88	38.43
7200	40	150	31.44	29.87	11.26	42.44
10800	40	150	31.70	30.08	11.78	44.07
14400	40	150	31.92	30.13	11.85	44.45
18000	40	150	32.06	30.19	11.73	45.41
21600	40	150	32.00	30.11	11.43	44.77
25200	40	150	31.50	29.84	11.46	44.97
Average	40	150	31.16	29.68	13.79	41.43

At the other days, the experimental data are not given here.

The experiments were conducted for 7 hours starting from 09.00 to 16.00 local time. The data shown in the Fig. 3 are the average of 3 days in each variation. Figure 3 indicates that increasing the length of the capillary tube decreases the COP. This was due to the increase in compressor work. At the same evaporator pressure, increasing the capillary tube length caused the high pressure in the condenser. As a result, the compressor work became

high. Meanwhile, the COP is equal to q_{in} divided by the compressor work, w_{in} , see equation (5), so that increase in the compressor work decreases the COP. The purpose of this study is to know the effect of capillary tube lengths on the water production; therefore, Fig. 4 presents the mass of the condensed water.

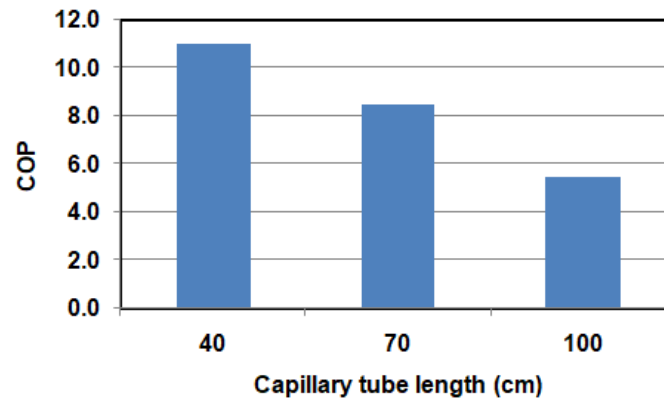


Figure 3. Average COP of three different capillary tube lengths

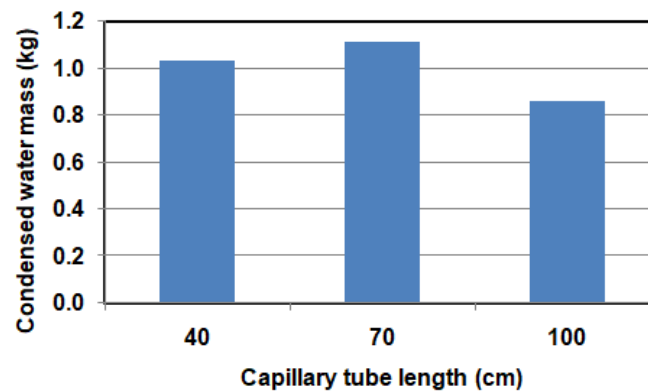


Figure 4. Condensed water mass obtained for 7 hours

Figure 4 shows that increasing the capillary tube length does not always increase or decrease the condensed water mass. In this study, the largest condensed water mass produced is obtained using the capillary tube length of 70 cm.

IV. CONCLUSION

An experimental study to investigate the effect of capillary tube lengths on water production of an air-water harvester was conducted. Based on these experimental conditions, the effect of capillary tube lengths on water production is not clear, since there is no trend of the water production respecting to the increase in the length of the capillary tube. The recommended length of the capillary tube to use is 70 cm.

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