International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

Vol. 33 No. 2 July 2022, pp. 304-311

Evaporator Pressure Effects On Water Production Of A Simple Air Water Harvester

M. Mirmanto[1], Rudy Sutanto[2], Ibnu Adnan Prasetya[3]

[1]Mechanical Engineering Department, Faculty Engineering, the University of Mataram
Jl. Majapahit no. 62, Mataram, 83125, NTB, Indonesia
mmirmanto@gmail.com
[2]Mechanical Engineering Department, Faculty Engineering, the University of Mataram
Jl. Majapahit no. 62, Mataram, 83125, NTB, Indonesia
r_sutanto10@yahoo.com
[3]Mechanical Engineering Department, Faculty Engineering, the University of Mataram
Jl. Majapahit no. 62, Mataram, 83125, NTB, Indonesia
iaprasetya@yahoo.com

Abstract—Water is a fundamental human need that is very important and must be met in everyday life. During the dry season, a number of areas in Indonesia encounter droughts which result in scarcity and difficulty in obtaining clean water. Therefore, research on air-water harvester needs to be carried out to determine the performance of this machine and in order to increase its water production. This research examines the effect of evaporator pressure on the mass of water production. The evaporator pressures varied were 30 psi, 40 psi and 50 psi. The refrigerant used was R134a for environmental friendly purposes. The specification of the compressor used was a compressor with a power of 1/2 PK. The results show that the highest water production mass was obtained at a pressure variation of 30 psi with an average mass of 0.4384 kg. The lowest water mass of 0.1773 kg was attained at a pressure variation of 50 psi. The highest COP of 25.29 was obtained at a pressure variation of 30 psi and the lowest COP was 10.84 at a pressure variation of 40 psi.

Keywords—water; pressure; evaporator; air water harvester; COP; R134a

I. INTRODUCTION

Water is a basic human need that is very important and must be met in everyday life. During the dry season, a number of areas in Indonesia experience many droughts which result in scarcity and difficulty in obtaining clean water. In fulfilling the water, humans make various efforts to get it. The fulfillment of clean water in question is water for consumption (drinking water), as well as for other household needs. Sources that are usually used to obtain this water include rainwater, river water, lakes, springs, or well water. Some of these water sources certainly require prior processing so that the water is fit for consumption [1].

One way to get clean water is by catching water from the air. According to Damanik [2], currently there are several methods of catching water from the air, including:

a) Windmills that catch water from the air. This windmill is devoted to producing water instead of electricity. It has several drawbacks, namely it requires a height and installation location that has a large wind speed to be able to move the mill, it really depends on the weather, wind speed, altitude, and wind direction. The installation cost is also quite expensive.

b) Water catching net from fog. Is a tool used to catch water from the fog using the help of nets designed in such a way that it is able to catch water from the fog. The net is made of woven plastic which is then connected to small pipes. This method has the disadvantage that the water obtained is relatively small.

c) Machines producing water from air use a vapor compression cycle component. Is a machine that produces water from air that uses components from the cooling machine including: compressor, condenser, capillary tube and evaporator. Dew water is produced in a section called the evaporator. The evaporator will absorb heat from the ambient air through the evaporator fins. As a result, the air temperature will decrease and experience cooling and condensation. Drops of water that fall due to the condensation process will be accommodated in a reservoir.

The third method is the easiest way to do and can be used by households with power that is still able to be supplied. This machine can be used to condense water vapor in the air. However, this cooling machine needs to be modified in the evaporator section so that it can be specifically used to condense water vapor.

Dirgantara [3] conducted a research to make a device that produces water from the air using an Air Conditioner cooling system with a power of 0.5 PK, and refrigerant R-134a. The average amount of water produced by the machine that produces water from air in the vertical evaporator variation is 343.2 grams which is the result of the highest amount of water in the study. The evaporator used by Dirgantara [3] in this study had a length of 60 cm, a width of 32 cm, and a diameter of 6.35 with an evaporator pressure of 40 psi.

Najib [4] has conducted research on air conditioning systems with variations in the length of the capillary tube 40 cm, 70 cm and 100 cm with a diameter of 0.25 in or equal to 6.35 mm with refrigerant R-134a. The study was conducted by maintaining a pressure of 40 psi. The results obtained from this study are the variation of the shortest capillary pipe, which is 40 cm, produces a water capacity of 1,097 kg, while in the variation of the longest capillary pipe, 100 cm, the water capacity obtained is 0,823 kg.

Monica [5] conducted research on a water harvesting machine from the air using an AC component consisting of a compressor with 1 PK power, a condenser, a capillary tube, and an evaporator. This tool works using a vapor compression cycle. The research uses R22 refrigerant with the addition of 2 fans and 1 blower in front of the evaporator which functions to condense the air. Variations are made on the equipment used to introduce air, namely: (a) 2 fans with 1 blower, (b) 1 fan with 1 blower, (c) 1 blower. The results showed that: The water harvester from the air that produces the largest volume of water has a Win value of 45.1 kJ/kg, a Qin value of 103.8 kJ/kg, a Qout value of 148.9 kJ/kg, an actual CO value of 2,302. , the ideal COP value is 4.296, the efficiency value is 53.57%. The amount of water produced by the water harvesting machine from the air is 2,692 liters/hour (with 2 fans and 1 blower), 2,284 liters/hour (with 1 fan and 1 blower), 1,867 liters/hour (with 1 blower). The pressure used in this study was 97 psi.

Atmoko [1] conducted research using an Air Conditioner cooling system that works with a vapor compression cycle consisting of a 1.5 PK compressor, an air cooled condenser, a capillary tube with a diameter of 0.028 inches and a length of 40 cm, and an evaporator with a finned pipe type. The refrigerant used in this research is R22 type. The modification applied to the research is to use 3 fans which function to compress the air with a power of 72.6 watts, cool the condenser with a power of 35.2 watts and dissipate the heat of the condenser to the outside environment with a power of 66 watts. The highest water yield that can be produced by the machine that produces water from the most air is the variation of the fan rotation speed of 350 rpm, which is 4.2915 liters/hour. The research was conducted with an evaporator pressure of 68 psi.

Mirmanto et al. [6] have conducted a study entitled the effect of the number of vertical evaporator pipes on the mass flow rate of water condensed from the air. The results showed that: (a) the machine that produces water from air can work well, (b) the characteristic values of the vapor compression cycle engine are as follows: (1) in variations of 25 evaporator pipes the highest COP value is 8.867, (2) the highest total heat absorbed by the evaporator from the air occurs in variations of 75 vertical evaporator pipes, which is 145.912 W, (3) the highest evaporator efficiency value of 12.524% is obtained with a 75 pipe evaporator, (4) the most water produced is 0.5043 kg on a 75 pipe evaporator.

Mirmanto et al. [7] performed experimental study on an air-water harvester machine for cooling drinking water. 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.

Mirmanto et al. [8] perform an experimental study of an air water harvester with capillary tube length variations. This technology condenses water vapor in the air using a vapor 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.

The literature search only obtained some literature related to this research, and there was no literature that had examined the effect of pressure on the mass of water produced. As in the paragraph above, it seems that previous researchers have not investigated the effect of evaporator pressure on the amount of dew produced. For refrigerant R22 they use a pressure of 68-97 psi. As for the R134a they use an average pressure of 40 psi. However, they do not vary the evaporator pressure. Meanwhile, the refrigeration machine operates between two pressures, namely low pressure in the evaporator and high pressure in the condenser. The difference in the pressure setting on the evaporator will result in a temperature difference in the evaporator. The difference in temperature will affect the mass of dew produced. Therefore, the authors are interested in studying the effect of evaporator pressure on the mass of water produced. The evaporator pressures to be varied are 30 psi, 40 psi and 50 psi. The reason for using an evaporator pressure of 40 psi is because previous studies using R134a mostly used that pressure. Then the selection of pressures of 30 psi and 50 psi is on the basis that pressure differences from 30 psi to 40 psi and from 40 psi to 50 psi are expected to be sufficient to produce different masses of water. The compressor as a component that will be used is a compressor with a power of 1/2 PK.

II. MATERIALS AND METHOD

The machine in this research is called air water harvester (AWH) presented in figure 1. The AWH is neither an air conditioner (AC) nor a refrigerator. Indeed, the names of the components used are the same as the names of the components on an air conditioner or refrigerator. The AC machine uses the temperature setting on the evaporator (indoor) section where when the room temperature has reached the setting temperature, the AC machine will turn off and when the room temperature rises, the AC machine will turn on again. Likewise the refrigerator, the refrigerator is also set at a certain temperature so that it does not continue to work. When the temperature setting is reached, the refrigerator will also turn off. This machine has no settings because it is expected to live continuously for 24 hours.

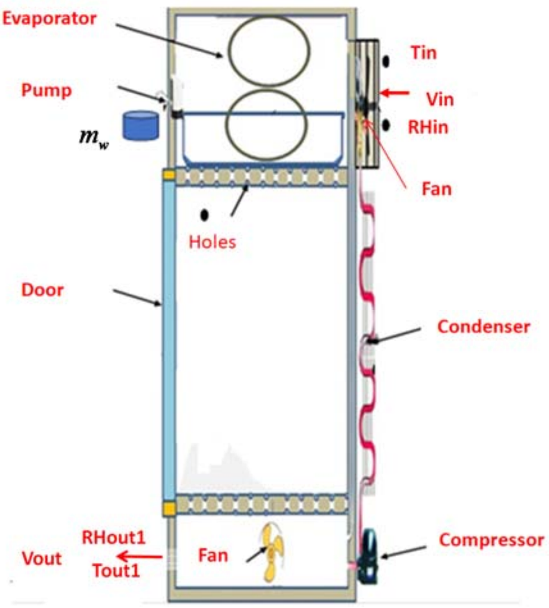

Fig. 1. Experimental apparatus

The pressure of the condenser unit (evaporator) is set according to the research objectives, namely at 3 different pressures, i.e. 30 psi, 40 psi and 50 psi. The reason for choosing the pressures has been explained in the introduction. Previous studies for R134a, the pressure used were 40 psi, as in the Dirgantara [3] and Najib [4] research. Meanwhile, if R22 is used, then the evaporator pressure used is ranging from 68 to 97 psi, as in the research of Atmoko [1] and Monica [5]. However, the reason for choosing 30 psi and 50 psi of pressures is expected to produce significantly different masses of water production at least 5% of the mass of water produced at a pressure of 40 psi. The pressures were measured directly using pressure gauges with measurement resolution of 5 psi. All temperatures were recorded using K-type thermocouples that connected to the data logger. The uncertainty of the temperature is ± 0.5°C.

This machine works by sucking air from the environment and then blowing it in through the top air hole and the air flows into the condensing chamber where the evaporator is located. The room is called the condensation room because the process of condensation of water vapor carried by the air occurs there. The air touches the walls of the evaporator which has a low temperature so that some of the water vapor in the air condenses, and the condensate drips into the water bath. Then the air flows down through the tiny holes, and is finally blown out with the fan below.

To analyze the experimental results, some equations below are implemented. The electric power needed by the compressor is not only for the gas compression process by the compressor itself, but also to overcome mechanical problems, friction, pipelines, gas leaks and others. To determine how much electrical power is needed for the compression process as follows:

$$P_c = VIF_p \tag{1}$$

P_c is the electrical power supplied to the compressor (W), V is the electrical voltages (V) and I refers to electrical current (A), while F_P is the power factor, which is a power factor whose amount will be read on the power meter measuring instrument, usually in the range of 0.7 to 0.9, but later what is used is only what is shown by the measuring instrument.

Cengel dan Boles [9] explained that compressor work per refrigerant mass could be calculated as:

$$w_i = h_2 - h_1 \tag{2}$$

w_i is the compressor work (J/kg), h_1 and h_2 are the enthalpies of refrigerant at the stae 1 and 2 (J/kg). The states can be seen in figure 2.

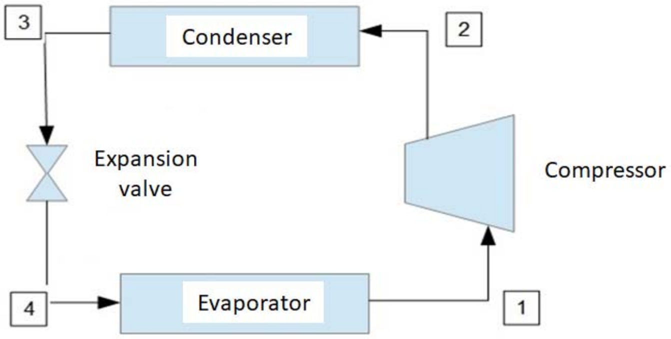

Fig. 2. Schematic diagram of process

According to Cengel and Boles [9], the energi rejected from the condenser could be estimated using equation below, which was used by Mirmanto et al. [6-8].

$$Q_o = h_2 - h_3 \quad (3)$$

Q_o represents the energy rejected from the condenser (J/kg), h_3 is the enthalpy of refrigerant at state 3, (J/kg). Meanwhile, the energy absorbed by the evaporator is expressed by equation (4) than can be obtained in [9].

$$Q_i = h_1 - h_4 \quad (4)$$

Q_i is the energy absorbed by the evaporator (J/kg), h_4 is the enthalpy of refrigerant at the stae 4, (J/kg). Cengel and Boles [9] also stated that the performance of the refrigeration machine could be examined using equation (5). The performance can be noted as coefficient of performance (COP).

$$COP = Q_i / w_i \quad (5)$$

Unfortunately, as there was no device to measure the mass flow rate of refrigerant, then the refrigerant mass flow rate can be predicted using the equation (6), which was utilized by several previous researchers, e.g. Dirgantara [3], Najib [4], Mirmanto et al. [6-8].

$$\dot{m}_{ref} = P_c / w_i \quad (6)$$

$\dot{m}_{ref}$ is the refrigerant mass flow rate (kg/s). According to Mirmanto et al. [6] the heat transfer rate from the dry air could be writtes as:

$$\dot{Q}_{da} = \dot{m}_{da} c_{pda} \left(T_{ai} - T_{ao}\right) \quad (7)$$

$\dot{Q}_{da}$ is the heat rate from dry air (W), $\dot{m}_{da}$ is the mass of dry air (kg), c_{pda} is the specific heat energy for the dry air (J/kg K), and T_{ai} and T_{ao} are the inlet and outlet air temperatures (°C).

In addition to the heat of dry air, there is also heat from water vapor being cooled and heat from water vapour becoming water.

$$\dot{Q}_{vp} = \dot{m}_{vp} c_{pvp} \left(T_{ai} - T_{ao}\right) \quad (8)$$

$\dot{Q}_{vp}$ is the heat rate from the water vapor absorbed by the evaporator (W), $\dot{m}_{vp}$ is the vapour mass flow rate (kg/s), c_{pvp} represents the specific heat of the vapour (J/kg K). The value of c_p is evaluated at T_{aa} (average air temperature).

$$T_{aa} = \left(T_{ai} + T_{ao}\right)/2 \quad (9)$$

$$\dot{Q}_w = \dot{m}_w h_{fg} \quad (10)$$

$$\dot{m}_w = m_w / t \quad (11)$$

$\dot{Q}_w$ is the heat from the condensed vapor (W), $\dot{m}_w$ is the mass flow rate of water production (kg/s), m_w is the mass of water production (kg), t is the total time of running AWH machine (s), and h_{fg} is the evaporation/condensation energy (J/kg).

The total heat absorbed by the evaporator from the cooled air can be calculated using the equation:

$$\dot{Q}_t = \dot{Q}_{da} + \dot{Q}_{vp} + \dot{Q}_w \quad (12)$$

Now the heat transfer rate from the evaporator absorbed by the refrigerant can be calculated using equation (13).

$$\dot{Q}_i = Q_i \dot{m}_{ref} \quad (13)$$

$\dot{Q}_i$ is the heat transfer rate absorbed by the refrigerant (W). Hence, the efficiency of the evaporator can be obtained as

$$\eta = \dot{Q}_t / Q_i \quad (14)$$

III. RESULTS AND DISCUSSION

This study was to determine the effect of evaporator pressure on the amount of water produced from the air in the air-water harvester machine. Therefore, there are several stages that need to be analyzed both on the refrigerant side and on the air side. Compressor work (w_i) can be obtained from the reduction between the enthalpy of the refrigerant at the state 2, h_2, and the enthalpy of the refrigerant at the state 1, h_1. To find out how the compressor works, first look for the enthalpy at each point, namely point 1 (evaporator to compressor), point 2 (compressor to condenser), point 3 (condenser to capillary tube) and point 4 (capillary pipe to evaporator).

The results of the tests that have been carried out to determine the amount of water produced from the air using the air-water harvester are presented in the form of graphs. Data collection was carried out for 7 hours starting from 09.00 to 16.00 local time for each variation. The following 4 graphs are displayed, namely the amount of water produced (m_w), the coefficient of performance (COP), the total heat absorbed by the evaporator from the cooled air ($\dot{Q}_t$), and the efficiency of the evaporator (η). COP is the ratio of the heat load to the compressor work and it is presented in figure 3.

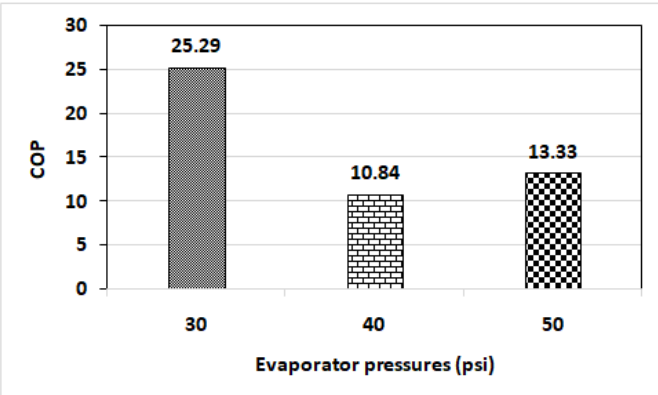

Fig. 3. The experimental COP for the three cases

As shown in figure 3, the effect of evaporator pressures on the COP is not clear, because it decreases from the pressure of 30 psi to the pressure of 40 psi, but it increases from the pressure of 40 psi to the pressure of 50 psi. This needs further clarification to answer the trends of COP. The highest COP occurs at a pressure variation of 30 Psi, namely 25.29. This is because at a pressure of 30 Psi, the average compressor work (w_i) and heat absorbed by the evaporator (Q_i) is greater than the other variations. The average compressor work (w_i) with a pressure of 30 Psi, 40 Psi and 50 Psi is 6.70 kJ/kg, 14.66 kJ/kg and 11.41 kJ/kg. Meanwhile, the energy absorbed by the evaporator (Q_i) with pressures of 30 Psi, 40 Psi and 50 Psi were 152.58 kJ/kg, 149.05 kJ/kg and 143.02 kJ/kg.

Meanwhile, figure 4 indicates the mass of water production and the effect of evaporator pressures on water production is clear. Increasing the evaporator pressure decreases the mass of water production. This was due to the evaporator temperature. Increasing the pressures increases the evaporator temperatures, so that the condensed water decreases. Figure 4 shows that in the evaporator with a pressure of 30 psi, the machine produces the most mass of water, which is 0.438 kg, while at a pressure of 40 psi, the machine produces a mass of water as much as 0.238 kg and at a pressure of 50 psi, the mass of water produced is 0.177 kg.

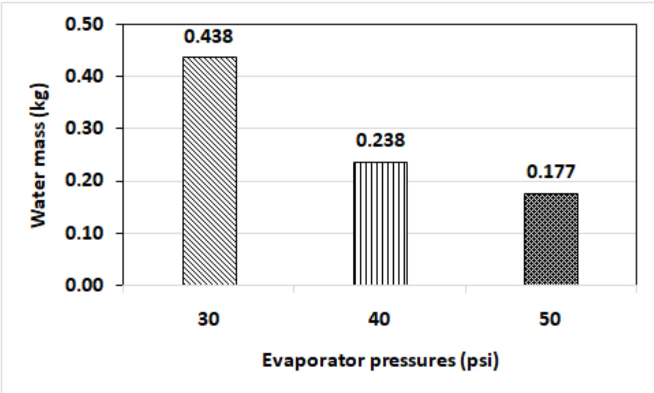

Fig. 4. The mass of water production for the three cases

Figure 5 shows that the highest average total heat absorbed by the evaporator from the cooled air is found at a variation of 30 psi, and the lowest average total heat absorbed by the evaporator from the cooled air is at a variation of 50 psi. This is caused by the difference in air temperature inlet and air out and the mass flow rate of dew, vapour in and dry air is higher at 30 psi variation compared to other variations. The average heat flow rate absorbed from dry air, vapour and dew for a pressure variation of 30 psi is 73.39 J/s, 2.87 J/s and 42.32 J/s.

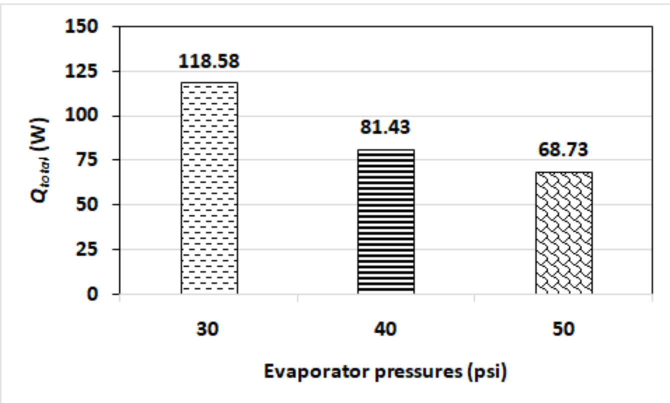

Fig. 5. The total heat transfer rate from the air

Figure 6 indicates that the difference in efficiency is not significant, meaning that the difference is not much, especially at pressures of 30 psi and 50 psi. The highest efficiency occurs at a pressure variation of 40 psi, this is because the average value of compressor power (P_c) is low so that the refrigerant mass flow rate is low and the heat flow rate absorbed by the evaporator ($\dot{Q}_i$) is low (calculation from the refrigerant side). While the lowest efficiency occurs at a pressure variation of 50 psi.

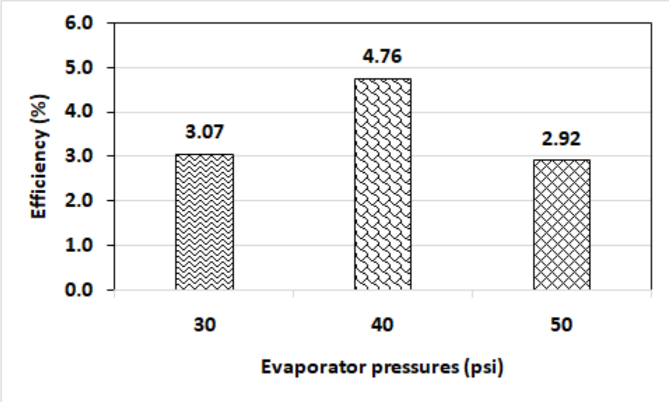

Fig. 6. The experimental evaporator efficiency

IV. CONCLUSION

Based on the results of research and analysis, it can be concluded that the pressure on the evaporator has an influence on the amount of water produced, with the highest water yield, namely at a pressure variation of 30 psi with an average water of 0.4384 kg. While the lowest average water yield occurred at a pressure variation of 50 psi of 0.1773 kg. So based on these results, the recommended evaporator pressure is 30 psi. The experimental COP and efficiency need further investigations.

V. ACKNOWLEDGMENT

The authors would like to acknowledgment the Mechanical Engineering Department, Engineering Faculty, the University of Mataram for the facility.

REFERENCES

[1] Y.W.T. Atmoko, "Karakteristik mesin penghasil air dari udara menggunakan mesin siklus kompresi uap dengan tambahan kipas pemadat udara berkecepatan putaran kipas 300 rpm dan 350 rpm," Thesis, Fakultas Sains dan Teknologi Universitas Sanata Dharma Yogyakarta, 2018

[2] Y.V. Damanik, "Pengaruh kecepatan putaran kipas terhadap performansi mesin destilasi air dari udara menggunakan siklus kompresi uap," Thesis, Fakultas Sains dan Teknologi Universitas Sanata Dharma Yogyakarta, 2018.

[3] R.P. Dirgantara, Pengaruh posisi evaporator terhadap jumlah air embun yang di hasilkan dengan menggunakan sistem kompresi uap," Thesis, Mechanical Engineering Department, Engineering Faculty, the University of Mataram, 2021.

[4] A.A. Najib, "Pengaruh variasi panjang pipa kapiler terhadap air yang dihasilkan dari udara menggunakan sistem kompresi uap," Thesis, Mechanical Engineering Department, Engineering Faculty, the University of Mataram, 2021.

[5] T. Monica, "Pengaruh adanya blower dan kipas terhadap karakteristik mesin pemanen air dari udara," Thesis, Mechanical Engineering Department, Engineering Faculty, the University of Mataram, 2021.

[6] M. Mirmanto, S. Syahrul, A.T. Wijayanta, A. Muliyanto, and L.A. Winata, "Effect of evaporator numbers on water production of a free convection air water harvester," Case studies in thermal engineering, 72, pp. 1-11, 2021. https://doi.org/10.1016/j.csite.2021.101253.

[7] M. Mirmanto, N. Nurchayati, and I. Afriani, "Performance of air-water harvester machine for cooling drinking water," IOSR Journal of Mechanical and Civil Engineering, 19, 1-6. 2022.

[8] M. Mirmanto, M. Wirawan, and A. Najib, "Effect of capillary tube length on mass of water production", International Journal of Advances in Engineering and Management, 4, 210-216, 2022.

[9] A.Y. Cengel, and A.M. Boles, Thermodynamic an Enggineering Approach, second ad, McGraw Hill Lnc., USA, 1994.