Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Effect of Coil Evaporator Positions on Freshwater Production and Heat Transfer Rate

Mirmanto Mirmanto[1,*], Nurchayati Nurchayati[1], Zulvavril Tri Handaru[1]

[1] Department of Mechanical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit no. 62, Mataram, NTB, 83125, Indonesia

ARTICLE INFO

Article history:
Received 14 June 2023
Received in revised form 8 September 2023
Accepted 20 September 2023
Available online 8 October 2023

Keywords:
Air-water harvester; evaporator position; freshwater production; heat transfer rate

ABSTRACT

Human life cannot be separated from water; therefore, water must be fulfilled because it is a basic human need. In the dry season, several regions in Indonesia experience a clean water crisis. This crisis needs to be overcome with methods or equipment that can produce water. Various methods for obtaining clean water were carried out in previous research, but not all methods were suitable for the current condition of Indonesia's territory. One method that could be used in all positions and situations and was suitable for household scales was an air-water harvester machine using a cooling machine. However, this method resulted in less freshwater production. Therefore, the authors were interested to examine the effect of the evaporator positions on the freshwater production and heat transfer rates. This research was carried out experimentally with the working fluid refrigerant R134a. The compressor used was a rotary type 1 PK compressor. This study varied the positions of the coil evaporator, namely the vertical position, the 45° position, and the horizontal position. The highest freshwater production and heat transfer rate were attained using the vertical position. The maximum freshwater production and heat transfer rate were 0.641 kg and 127.17 W respectively.

1. Introduction

In all human activities, water is a basic need such as household needs, for example for drinking, cooking, bathing, washing, industrial needs, trade needs, agricultural and animal husbandry needs, shipping needs and so on. When the dry season arrives, some areas in Indonesia experience a clean water crisis, as happened in several areas in South Kuripan Village, Kuripan District, West Lombok Regency, Central Lombok, NTT and parts of Central and East Java. Therefore, it takes some method or equipment to produce water.

Various methods of obtaining clean water have been reported in previous studies, such as purifying dirty or waste water, seawater distillation, reverse osmosis, dew harvesting using nets, and dew harvesting using windmills. Seawater distillation is an easy way to do it, but requires high energy unless the energy used comes from the sun. In addition, this method cannot be applied in highland

* *Corresponding author.*
E-mail address: m.mirmanto@unram.ac.id

https://doi.org/10.37934/arfmts.110.1.97103

areas or far from the sea. Catching dew with a net can be maximized if the net is placed in a zone that has a lot of moisture. The use of windmills is not suitable for residents with a low economic level, except for residents who have a higher economy or the government, because it is expensive to manufacture. An alternative method that can be used in all places and conditions, and is suitable for the household scale is to convert water vapor into dew using a cooling machine as reported in Mirmanto *et al.,* [1] which is often called an air-water harvester machine using the working principle of the vapor compression cycle.

Much research on air-water harvester machines has been carried out, such as by Mirmanto *et al.,* [1,2], Atmoko [3], Gaol [4], and Ahmad [5]. Atmoko [3] researched a water-producing machine using a 1.5 PK AC engine with the original evaporator from the AC machine itself and producing 4.29 liters of water/hour. Gaol [4] conducted research on a water-producing machine using an AC machine with 3/4 PK power, refrigerant type R410a obtained a yield of 2.01 liters/hour and Ahmad [5] examined an air-water harvester made of copper pipes and a parallel evaporator. The refrigerant used is R134a and the compressor used is a rotary type 1/2 PK compressor. This research produces water of 0.369 kg/7 hours. Mirmanto *et al.,* [2] examined the effect of evaporator diameters on performances of a custom air water harvester. Mirmanto *et al.,* [2] used a parallel evaporator, R134a refrigerant and 1/2 PK compressor power and air flow was assisted by a fan. The water yield obtained was only 0.369 kg/7 hours of experiment. Ibnu [6] also conducted research on a water-producing machine with a spiral-shaped evaporator and air entering at a speed of 2.2 m/s. The machine uses R134a and the compressor power is 1/2 PK. The results obtained were still small, namely 0.4384 kg/7 hours. Meanwhile, Ridho [7] conducted research using an evaporator in the form of vertical pipes, 1/2 PK compressor power, and R-134a refrigerant. Aerospace research variations are the evaporator position, namely vertical, 45° and horizontal. The results obtained were 0.3537 kg/7 hours.

Universally, the research results that were carried out above were the original AC evaporator, parallel evaporator and coil evaporator. Then there was only one study that examined the position of the evaporator, namely Ridho [7] while the other was the heat transfer systems such as natural convection, and forced convection. However, no one had examined the position of the coil evaporator against the mass of freshwater produced by the forced convection system. For this reason, this study continued the study of Ibnu [6] by using a coil evaporator and following the study of Ridho [7] by varying the position of the evaporator.

2. Materials and Method

The experimental apparatus is given in Figure 1. The shape of the evaporator is the coil and the evaporator positions varied are vertical, inclined 45°, and horizontal. The apparatus contains a PVC tube (condensation room), a coil evaporator, a condenser, a compressor and a capillary tube. The air flowed through a fan and came into the condensation room where the coil evaporator was placed. Due to the cold evaporator wall, part of the water vapour contained in the air condensed. The condensate flowed down along the PVC tube and was collected using a bucket placed near the end of the PVC tube. The temperature of the evaporator walls is lower than the dew point. Then the air flows out from the condensation room through the bottom hole of the PVC tube.

All temperatures were measured using K-type thermocouples that were calibrated against the stainless steel thermometer probe that emerged in an oil bath. The measurement ranges of the thermocouple are -50°C to 1300°C and the uncertainty of the temperature measurements was ± 0.5°C obtained from the calibration. The relative humidity, ambient temperature and ambient pressure were detected using a digital hydro-barometer model Fj3373B. Meanwhile, the freshwater attained was weighed using a digital balancer model CAMRY 5055.

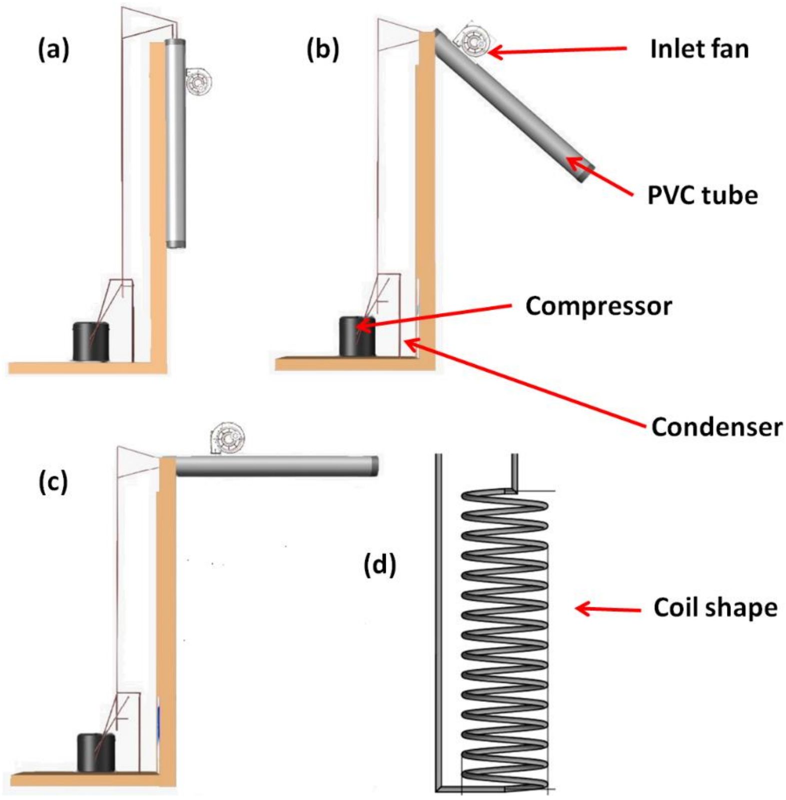

Fig. 1. Evaporator positions (a) vertically, (b) incline 45°, (c) horizontally, and (d) is the coil evaporator that is placed inside the PVC tube

To analyze the results, some equations are used. The mass flow rate of the freshwater is calculated using Eq. (1) which could be obtained in Mirmanto *et al.,* [1,2] and is written as

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

$\dot{m}_d$ is the mass flow rate of the dew or freshwater (kg/s), m_d is the mass of dew (kg), t is the time running of the machine (s). Meanwhile, the total mass flow rate can be estimated as

$$\dot{m}_t = \rho A V \tag{2}$$

$\dot{m}_t$ is the total mass flow rate of the air (kg/s), ρ is the density of the air (kg/m³) that can be obtained in the atmospheric air table based on the average air temperature. A is the inlet area (m²), and V is the air velocity at the entrance (m/s). The part of water vapour in the air can be known using an online psychometric chat that can be accessed in HVAC Calculator [8]. By inputting the parameter dry bulb temperature and relative humidity (RH) into HVAC Calculator [8], part of the water vapour can be found.

$$\dot{m}_t = \dot{m}_{da} + \dot{m}_v$$

$$\dot{m}_t = \dot{m}_{da} + w_1 \dot{m}_{da}$$

$$\dot{m}_{da} = \frac{\dot{m}_t}{1+w_1} \tag{3}$$

$\dot{m}_{da}$ is the mass flow rate of dry air (kg/s), $\dot{m}_v$ is the mass flow rate of water vapour at the entrance (kg/s) and w_1 is part of water vapour at the entrance (kg_v/kg_{da}) that can be obtained in HVAC Calculator [8]. Heat transfer rates from the air to the evaporator walls contain heat transfer rate from dry air, heat transfer rate from water vapour and heat transfer rate from dew or freshwater. The heat transfer rate from the dry air can be estimated using Eq. (4) which can be obtained in Çengel and Boles [9], Incropera *et al.,* [10], and Mirmanto *et al.,* [1,11-13].

$$\dot{Q}_{da} = \dot{m}_{da} c_{pda} \left(T_i - T_o\right) \tag{4}$$

$\dot{Q}_{da}$ is heat transfer rate from dry air (W), T_i and T_o are the inlet and outlet temperatures of the air (°C), and c_{pda} is the specific heat of the air (J/kgK). The parameter can be obtained from a table of air at atmospheric pressure based on the average air temperature, Eq. (5) that can be seen in Mirmanto *et al.,* [1,11].

$$T_{av} = \left(T_i + T_o\right)/2 \tag{5}$$

T_{av} is the average air temperature (°C). The heat transfer rate from the water vapour can be calculated using Eq. (6) which can be obtained in Mirmanto *et al.,* [1,11-13], Fauzan [14], and Sunaryono [15].

$$\dot{Q}_v = \dot{m}_v c_{pv} \left(T_i - T_o\right) \tag{6}$$

$\dot{Q}_v$ is the heat transfer rate from the water vapour (W), c_{pv} is the specific heat of the vapour (J/kg°C). Then, the heat transfer rate from the dew or freshwater can be determined using Eq. (7) which can be found in Mirmanto *et al.,* [11-13], Fauzan [14], and Sunaryono [15] and written as:

$$\dot{Q}_d = \dot{m}_d h_{lg} \tag{7}$$

$\dot{Q}_d$ is the heat transfer rate from the dew or freshwater (W), h_{lg} is the latent heat of condensation (J/kg). Then the total heat transfer rate from the air to the evaporator walls is equal to the sum of all heat transfer rates and it is expressed as:

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

Eq. (8) can be found in Mirmanto *et al.,* [1,2,11,12], Fauzan [14], and Sunaryono [15].

3. Results and Discussion

The data obtained on the online psychometric chart is the portion of water vapour in the air when it enters the evaporator (w_1), it requires the temperature of the air entering the evaporator and RH_i, by entering temperature and RH into the online psychometric chart: Free online Psychometric Calculator (HVAC-calculator .net), obtained data as shown in Table 1.

Table 1
The results of the psychometric chart calculation

Evaporator position	T_i (°C)	T_o (°C)	RH_i (%)	RH_o (%)	w_1 (kg_v/kg_{da})
Vertical	29.13	25.27	76.14	88.43	0.01947
45°	29.04	25.16	76.43	88.86	0.01944
Horizontal	28.64	24.66	77.71	89.71	0.01931

To get the value of w_1, the value of Tin and RH_i is needed, it is known that the value of T_i = 29.13°C and RH_i = 76.14, then the value of w_1 is obtained so that the value of w_1 = 0.01947 kg vapour /kg dry air = 19.47 g vapour/kg dry air. From the data obtained in the study, the following parameters can be calculated: the mass flow rate of condensed water ($\dot{m}_d$), the heat flow rate from dry air ($\dot{Q}_{da}$), the heat flow rate from dew or water ($\dot{Q}_d$), the heat flow rate from the cooled vapour ($\dot{Q}_v$), the mass flow rate of dry air ($\dot{m}_{da}$), the mass flow rate of incoming water vapour ($\dot{m}_v$), the total mass flow rate of air ($\dot{m}_t$), and the total heat flow rate absorbed by the evaporator ($\dot{Q}_t$).

The results of the average water mass are shown in Figure 2. The most water mass was produced by the vertical position evaporator with a total average mass of water produced as much as 0.653 kg, followed by the evaporator in position 45° with an average mass of water as much as 0.567 kg and horizontal position evaporator with the lowest average water mass obtained as much as 0.519 kg. As can be seen in Figure 2, the vertical position gets the most average mass of freshwater. This was because the vertical position could help the dew that bonded to the evaporator wall to fall more easily. The other positions did not help the dew to drop down. This phenomenon was also found by Ridho [7], who stated that the best position was vertical; however, the shape of the evaporator was different though. However, the difference of the freshwater production is significant between vertical and horizontal positions.

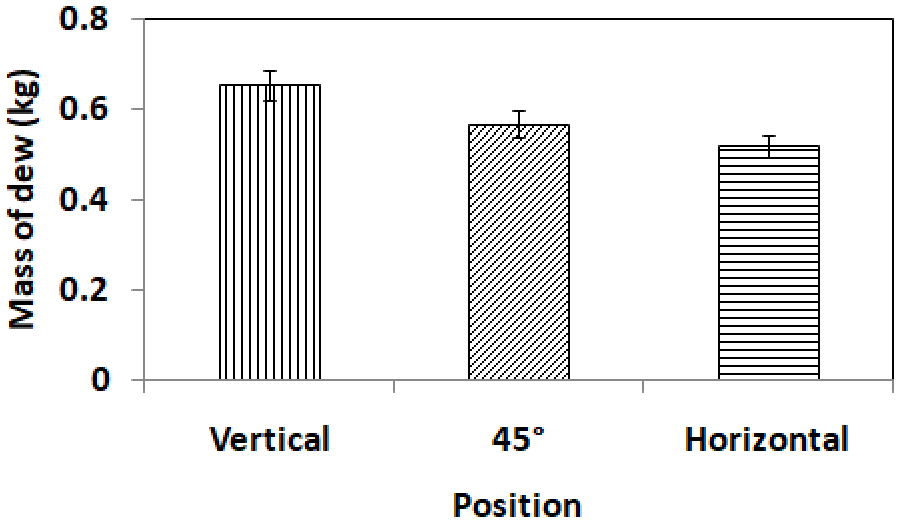

Fig. 2. The experimental freshwater mass for the three evaporator positions

Figure 3 shows that the highest total heat transfer rate ($\dot{Q}_t$) occurs in vertical position variations with the value of 127.17 J/s, while the 45° and horizontal positions result in 121.19 J/s, and 118.43 J/s respectively. This could happen because the vertical position variation had the highest $\dot{m}_d$, $\dot{m}_{da}$

and $\dot{m}_v$. Those are shown in Table 2. However, by adding error bars, the positions of the evaporator do not affect the heat transfer rate at the confidence level of 95%.

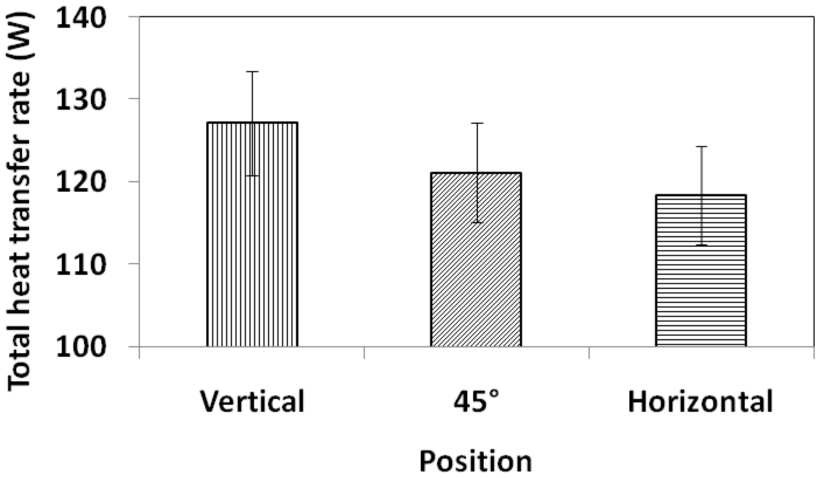

Fig. 3. The experimental total heat transfer rate for the three evaporator positions

Table 2
Calculation results of the heat flow rates

Evaporator position	m_d (kg)	$\dot{m}_d$ (kg/s)	$\dot{m}_t$ (kg/s)	$\dot{m}_{da}$ (kg/s)	$\dot{m}_v$ (kg/s)	$\dot{Q}_{da}$ (J/s)	$\dot{Q}_v$ (J/s)	$\dot{Q}_d$ (J/s)	$\dot{Q}_t$ (J/s)
Vertical	0.641	0.00002544	0.016523	0.01653	0.0003157	62.89	2.28	61.99	127.17
45°	0.574	0.00002278	0.016533	0.01622	0.0003153	63.38	2.29	55.52	121.19
Horizontal	0.527	0.00002091	0.016553	0.01624	0.0003136	65.09	2.34	50.99	118.43

4. Conclusions

The experimental investigation was conducted to know the effect of coil evaporator positions on freshwater production and the heat transfer rate. Based on the experimental data and analysis, the following conclusions can be drawn: (i) The vertical coil evaporator position results in the highest freshwater production and heat transfer rate, (ii) The maximum freshwater mass obtained is 0.641 kg, corresponding to the maximum total heat transfer rate of 127.17 W, (iii) To attain the high freshwater production, the vertical evaporator position is the most recommended. Based on the error bars with a confidence level of 95%, the effect of coil evaporator positions on heat transfer rate is not significant.

Acknowledgement
The authors would like to acknowledge the DRPM, and the Ministry of Education, Culture, Research, and Technology of Indonesia for the research grant years 2020 to 2023, and thank the University of Mataram for the facilities.

References
[1] Mirmanto, M., S. Syahrul, A. T. Wijayanta, A. Mulyanto, and L. A. Winata. "Effect of evaporator numbers on water production of a free convection air-water harvester." *Case Studies in Thermal Engineering* 27 (2021): 101253. https://doi.org/10.1016/j.csite.2021.101253

[2] Mirmanto, Mirmanto, Syahrul Syahrul, and Agung Wijayanta. "Effect of Evaporator Diameters on Performances of a Custom Air Water Generator." *Frontiers in Heat and Mass Transfer (FHMT)* 20 (2023). https://doi.org/10.5098/hmt.20.9

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

[4] Gaol, Clinton Lumban. "Mesin penghasil air dari dara dengan menggunakan komponen air conditioner 3/4 PK." *Bachelor Thesis, Department of Mechanical Engineering, Yogyakarta, Universitas Sanatha Dharma* (2019).

[5] Ahmad, Faroni. "Pengaruh Diameter Pipa Unit Pengembun Terhadap Massa Air Yang Dihasilkan Dari Air-Water Harvester." *PhD diss., Universitas Mataram*, 2022.

[6] Ibnu, Adnan Prasetya. "Pengaruh Tekanan Unit Pengembun Pada Mesin Air-Water Harvester Terhadap Massa Air Yang Dihasilkan." *PhD diss., Universitas Mataram*, 2022.

[7] Ridho, Pandu Dirgantara. "Pengaruh Posisi Evaporator Terhadap Jumlah Air Embun Yang Dihasilkan Dengan Menggunakan Sistem Kompresi Uap." *PhD diss., Universitas Mataram*, 2021.

[8] HVAC Calculator. "Psychrometric Calculator." *HVAC Calculator*, 2017. http://www.hvac-calculator.net/index.php?v=2.

[9] Çengel, Yunus A., and Michael A. Boles. *Thermodynamics: an engineering approach*. McGraw-Hill Higher Education, 1994.

[10] Incropera, Frank P., David P. DeWitt, Theodore L. Bergman, and Adrienne S. Lavine. *Fundamentals of heat and mass transfer*. New York: Wiley, 2006.

[11] Mirmanto, M., Made Wirawan, and Aban Najib. "Effect of capillary tube length on mass of water production." *International Journal of Advances in Engineering and Management* 4 (2022): 210-216.

[12] Mirmanto, M., N. Nurpatria, and J. K. Hendra. "Pengaruh suhu udara masuk terhadap massa air yang dihasilkan pada alat pemanen air sederhana." *Dinamika Teknik Mesin* 13, no. 1 (2023): 10-17. https://doi.org/10.29303/dtm.v13i1.617

[13] Mirmanto, Mirmanto, Made Wirawan, and Lazuardi Firdaus. "Effect of air velocities on the coil air water harvester performances." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)* 19, no. 6 (2022): 37-42.

[14] Fauzan, Muhammad. "Kinerja mesin air water harvester dengan unitpengembun paralel pada berbagai kecepatan udara masuk." *PhD diss., Universitas Mataram*, 2022.

[15] Sunaryono, Muhammad Fikri. "Kinerja Mesin Air-Water Harvester Dengan Unit Pengembun Spiral Pada Berbagai Kecepatan Udara Masuk." *PhD diss., Universitas Mataram*, 2022.