Effect of Air Velocity on the Performance of a Four-Coil Evaporator Atmospheric Water Harvester

An Experimental Study on Water Production, Energy Consumption, and System Efficiency at Varying Air Velocities

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***Abstract*—The increasing demand for clean water has driven the development of various technologies, including seawater reverse osmosis (SWRO), rainwater harvesting, and atmospheric water harvesting systems. Among these, atmospheric water harvesters operate using a vapor-compression refrigeration cycle to condense water vapor from ambient air. This study investigates the effect of air velocity on water production and heat transfer performance in a four-coil evaporator atmospheric water harvester. An experimental approach was employed using R134a as the working fluid and a 1 PK rotary compressor. The system was equipped with four coil-type evaporators, each with a tube diameter of 6.35 mm, 26 turns, and a coil diameter of 80 mm. Air velocity was varied at 4 m/s, 5 m/s, and 6 m/s. The results show that the highest water yield of 0.733 kg was obtained at an air velocity of 6 m/s over 7 hours of operation. The maximum heat transfer rate from air to the evaporator reached 290.778 J/s at an air velocity of 5 m/s. Meanwhile, the highest coefficient of performance (COPrev) of 9.21 was achieved under no-airflow conditions (0 m/s). These findings indicate that air velocity significantly affects water production, heat transfer, and overall system performance, with optimal conditions depending on the desired performance parameter.**

***IndexTerms*—Atmospheric water harvester, Air velocity, Water production; Heat transfer, Four-coil evaporator, Coefficient of performance (COP_{rev})**

I. Introduction

Various technologies have been developed to address the increasing global demand for clean water, particularly in response to the growing water scarcity crisis [1]. Common approaches include seawater reverse osmosis (SWRO), rainwater harvesting, and fog harvesting systems assisted by wind energy [2-4]. Nevertheless, each of these technologies presents inherent limitations. For example, SWRO and wind-assisted systems generally require high capital investment and operational costs [2]. Moreover, SWRO is primarily applicable in coastal regions or areas with access to saline or brackish water sources [2]. In contrast, rainwater harvesting systems are highly dependent on seasonal rainfall patterns, making them less reliable in regions with low precipitation [3]. Similarly, fog harvesting technologies tend to be effective only in high-altitude areas with high humidity and sufficient water vapor content [4].

As an alternative solution, atmospheric water harvester (AWH) technology offers greater flexibility, as it can be applied in a wide range of environmental conditions. This system extracts water directly from ambient air by condensing water vapor into liquid form through a refrigeration-based process. The system operates using a vapor-compression refrigeration cycle, in which the evaporator plays a critical role in absorbing heat from the air and facilitating condensation. According to Mirmanto et al. [5-6], AWH systems show strong potential for meeting household-scale water demands due to their independence from conventional water sources.

Numerous studies have been conducted to evaluate the performance of AWH systems under varying operating conditions. Djafar et al. [7], Suriatman et al. [8], and Mirmanto et al. [9-12] investigated system performance across different parameters. In addition, studies by Firdaus [13], Fauzan [14], and Irhami [15] specifically examined the influence of inlet air velocity on water production. These studies consistently indicate that air velocity is a key parameter affecting heat transfer rates and the amount of condensate produced.

However, most previous research has focused on single or parallel evaporator configurations. To address this limitation, the present study proposes the use of four coil-type evaporators to increase the effective heat transfer surface area. This work builds upon the research conducted by Firdaus [13], which utilized a single-coil evaporator. By increasing the number of evaporators to four units, it is expected that water production, heat transfer rate, and system performance—particularly the coefficient of performance (COPrev)—will improve.

Previous studies also provide important insights into system design parameters. Ardiansyah [16] investigated the performance of AWH with open and closed evaporator. The study used a ¼-inch diameter copper pipe evaporator with R134a refrigerant and a ½ PK compressor. Experiments were conducted over 7 hours at the Heat Transfer Laboratory, Faculty of Engineering, University of Mataram, with each variation repeated three times. The results demonstrated that evaporator orientation significantly affects water production.

Furthermore, Mirmanto et al. [5] examined the effect of the number of evaporators on water production and system performance. The evaporators, made of copper pipes (480 mm × 285 mm × 6.25 mm), were arranged in parallel within an open box system (500 mm × 500 mm × 500 mm). The system operated using R134a refrigerant at low and high pressures of 40 psi and 180 psi, respectively. Three configurations were tested: one, two, and three evaporators. Each evaporator consisted of 25 copper tubes with a length of 285 mm. The results showed that increasing the number of evaporators enhanced water production, with a maximum yield of 0.51 L over 7 hours.

Fauzan [14] investigated the performance of an AWH system using parallel condenser units and a 1 PK rotary compressor with R134a refrigerant. The study varied inlet air velocity at 0 m/s, 1.5 m/s, 3 m/s, and 4.5 m/s. The highest water production was obtained at an air velocity of 3 m/s, with an average of 0.869 kg over 7 hours. Meanwhile, the highest total heat transfer rate occurred at 4.5 m/s, reaching an average of 132.42 J/s.

In addition, Faroni [17] studied the effect of condenser pipe diameter on water production using a 0.5 PK rotary compressor and R134a refrigerant. The pipe diameters tested were 3.00 mm, 4.00 mm, and 6.35 mm. The results indicated that the highest water production, 0.369 kg over 7 hours, was achieved using a 3.00 mm diameter pipe. This configuration also produced the highest heat transfer rate, reaching 52.101 W.

II. Materials and Method

The experimental apparatus contains evaporator, condenser, centrifugal fans, capillary tube, compressor, condensation box, and bucket, as shown in Fig. 1. This study employed an experimental method to evaluate the performance of an atmospheric water harvester system under different operating conditions. The experimental approach allows for the investigation of system behavior by applying controlled variations to selected parameters and comparing the results under different treatment conditions. Devices and materials were prepared prior to the experiment to ensure smooth execution and avoid interruptions during data collection. The main components of the system include a compressor, condenser, evaporator unit, and capillary tube. Additional used in this study consist of a computer, thermocouples, an anemometer, a barometer, a data logger, a digital weighing scale, a water collection container, and a fan to control airflow. The working fluid used in the system was refrigerant R-134a.

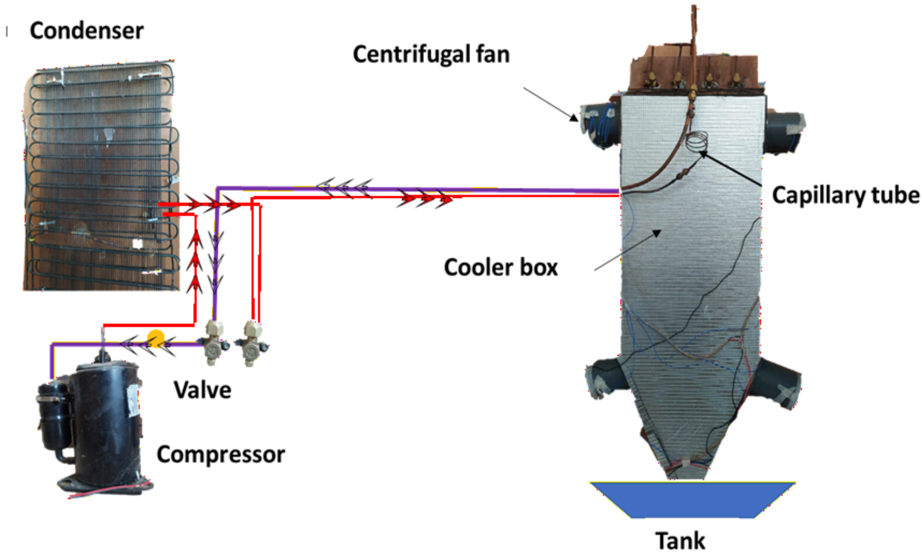

Figure 1. Schematic diagram of the apparatus

The variables considered in this study are classified into dependent and independent variables: Dependent variables are those measured during the experiment and analyzed to evaluate system performance. These include (i) Outlet air temperature, (ii) Outlet air relative humidity (RH), (iii) Mass of condensed water, (iv) Heat transfer rate from air to the evaporator. Independent variables are controlled and varied according to the objectives of the study. The independent variable in this research is the inlet air velocity, which was set at 0 m/s, 4 m/s, 5 m/s, and 6 m/s.

Prior to system operation, the data logger was activated to record initial air temperature and relative humidity. The desired air velocity was then set using a fan (e.g., 4 m/s). Afterward, the atmospheric water harvester system was turned on. Once steady operation was achieved, data were recorded periodically, including air temperature, relative humidity, inlet air velocity, compressor power consumption, and the mass of water collected every hour. Each experimental run was conducted for duration of 7 hours. To ensure data reliability, each test condition was repeated three times. The same procedure was applied for all variations of air velocity.

The refrigerant used was R134a, and temperatures were measured using k type thermocouples connected to data logger Applent 24 channels, and the air velocity was detected using a anemometer, while the mass of the freshwater gained was measured using a digital balancer.

III. Results and Discussion

The experimental investigation was conducted using a vapor-compression-based air–water harvester system to evaluate the effect of inlet air velocity on water production (m_d) and the total heat transfer rate absorbed by the evaporator (Q_t). The experiments were performed at four air velocity conditions, namely 0 m/s (natural convection), 4 m/s, 5 m/s, and 6 m/s (forced convection). Each test was repeated three times to ensure data reliability, resulting in a total experimental duration of 12 days. Data acquisition was carried out for 7 hours per day, from 08:00 to 15:00 WITA, under relatively consistent environmental conditions.

Figure 2 presents the average mass of water produced under different inlet air velocities. The results clearly demonstrate that air velocity has a significant effect on water production, as confirmed by the error bar analysis showing non-overlapping intervals. This indicates that the differences between test conditions are statistically meaningful.

The highest average water production was obtained at an air velocity of 6 m/s, reaching 0.733 kg over 7 hours. This was followed by 4 m/s (0.677 kg) and 5 m/s (0.644 kg). Meanwhile, the lowest performance was observed under natural convection (0 m/s), highlighting the importance of forced airflow in enhancing system productivity.

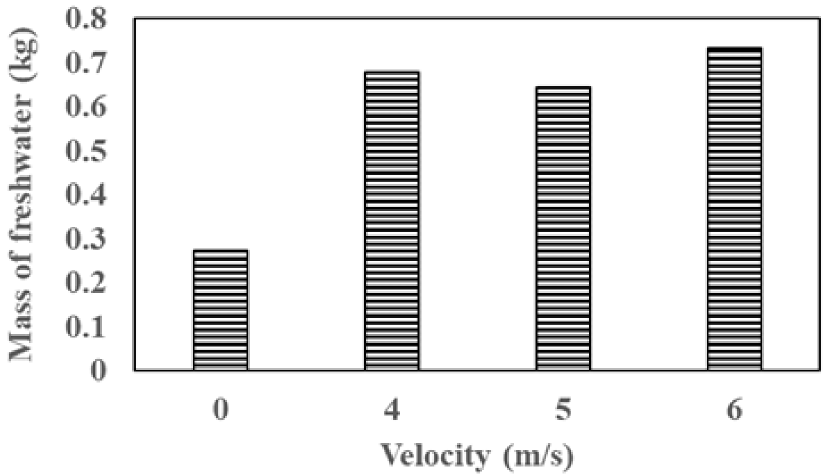

Figure 2. Relationship of freshwater mass and air inlet velocity

From a thermodynamic perspective, increasing air velocity enhances convective heat transfer between the moist air and the evaporator surface. This leads to a higher rate of sensible cooling, enabling the air temperature to reach the dew point more rapidly, thereby accelerating the condensation process [18]. In addition, higher airflow rates increase the mass flow rate of humid air entering the system, which directly increases the availability of water vapor for condensation.

However, it is important to note that the relationship between air velocity and water production is not strictly linear. Although 6 m/s yields the highest water mass, the result at 5 m/s is lower than at 4 m/s. This suggests the presence of competing mechanisms, such as reduced residence time of air within the evaporator chamber at higher velocities. When airflow becomes too fast, the contact time between air and the cold evaporator surface decreases, potentially limiting the condensation efficiency despite the increased mass flow rate.

When compared to previous studies, the present work shows a noticeable improvement in water production. Handaru [19] reported a maximum yield of 0.653 kg/7 hours, while Firdaus [13] obtained 0.622 kg/7 hours. In contrast, this study achieved an average of 0.710 kg/7 hours at optimal conditions. The improvement can be attributed primarily to system design modifications.

First, the use of four evaporator units significantly increases the effective heat transfer area. A larger surface area allows more air–surface interaction, thereby enhancing condensation rates [5]. Second, the use of dual fans increases airflow distribution and uniformity within the chamber, reducing stagnant zones and improving overall system effectiveness. Third, the addition of multiple air inlets enhances air intake capacity, ensuring a continuous supply of moist air into the system. These findings confirm that both airflow management and heat exchanger configuration play crucial roles in optimizing atmospheric water harvesting performance.

Figure 3 shows the average total heat transfer rate absorbed by the evaporator under different air velocity conditions. Similar to water production, the error bar analysis indicates that air velocity significantly influences the heat transfer rate. In general, increasing air velocity enhances convective heat transfer due to a higher Reynolds number, which reduces the thermal boundary layer thickness and increases the heat transfer coefficient [20]. As a result, more heat is removed from the air, facilitating both sensible and latent heat transfer processes.

Interestingly, the highest heat transfer rate was observed at 5 m/s rather than 6 m/s. This phenomenon can be explained by examining the enthalpy difference between inlet and outlet air conditions. At 5 m/s, the system achieves a more optimal balance between airflow rate and heat exchange effectiveness, resulting in a larger enthalpy drop. In contrast, at 6 m/s, although the airflow rate is higher, the reduced residence time limits the extent of cooling and condensation, leading to a slightly lower overall heat transfer rate.

The total heat transfer rate in this study reached 290.78 J/s, which is significantly higher than the results reported by Firdaus [13] at 161.71 J/s and Handaru [19] at 124.16 J/s. This substantial improvement further supports the effectiveness of the multi-evaporator configuration.

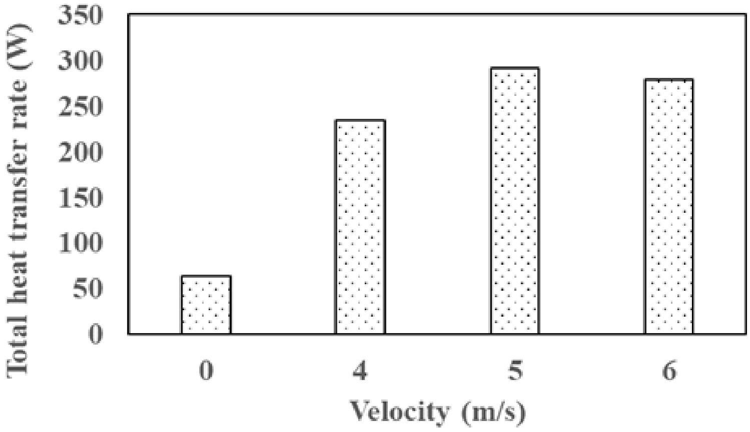

Figure 3. Relationship of total heat transfer rate and air inlet velocity

From a physical standpoint, the enhancement can be explained by improved refrigerant distribution and thermal uniformity across the evaporator coils. As reported by Wang et al. [21], uniform refrigerant flow ensures that all evaporator tubes maintain a consistently low temperature, maximizing condensation across the entire surface. This leads to an increase in all components of heat transfer, including sensible heat, latent heat, and condensate heat.

Furthermore, the presence of multiple evaporators reduces thermal resistance within the system and improves overall heat exchanger effectiveness. This aligns with fundamental heat transfer theory, where increasing surface area and enhancing convection are key strategies for improving thermal performance [20].

Overall, the results suggest that there exists an optimal range of air velocity that balances airflow rate and heat transfer effectiveness. Excessively low velocity limits the supply of water vapor, while excessively high velocity reduces contact time and system efficiency. Therefore, system optimization should consider both aerodynamic and thermodynamic factors simultaneously.

In addition, the integration of multiple evaporators and improved airflow design represents a promising approach for scaling up atmospheric water harvesting systems. Future work may focus on optimizing evaporator geometry, refrigerant type, and control strategies to further enhance system performance and energy efficiency.

IV. Conclusion

This study confirms that the performance of a vapor-compression-based atmospheric water harvester (AWH) is strongly influenced by inlet air velocity and evaporator configuration. The highest water production was obtained at an air velocity of 6 m/s, reaching 0.733 kg over 7 hours, while the maximum heat transfer rate of 290.78 J/s occurred at 5 m/s. These results indicate that increasing air velocity enhances heat transfer and condensation, although excessively high velocity may reduce effectiveness due to shorter air residence time. The use of four evaporator units significantly improved system performance compared to previous studies, increasing the average water production to 0.710 kg/7 hours, higher than earlier results (0.622–0.653 kg/7 hours). This improvement is attributed to the increased heat transfer surface area and better airflow distribution. Overall, optimal airflow and multi-evaporator design are key factors in enhancing AWH efficiency, making this system a promising solution for decentralized freshwater production.

References

[1] P.H. Gleick, “The world’s water”, vol. 8, The biennial report on freshwater resources, Island Press, 2014.

[2] N. Ghaffour, T.M. Missimer, and G.L. Amy, “Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability”, Desalination, 309, 197–207, 2013.

[3] A. Campisano, D. Butler, S. Ward, M.J. Burns, E. Friedler, K. DeBusk, L. Fisher-Jeffes, E. Ghisi, A. Rahman, H. Furumai, and M. Han, “Urban rainwater harvesting systems: Research, implementation, and future perspectives”, Water Research, 115, 195–209, 2017.

[4] M. Fessehaye, S.A. Abdul-Wahab, M.J. Savage, T. Kohler, and T. Gherezghiher, “Fog-water collection for community use”, Renewable and Sustainable Energy Reviews, 29, 52–62, 2014.

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

[6] M. Mirmanto, S. Syahrul, I.W. Joniarta, A. Azari, A. Fahroni, M. Mara, N. Nurpatria, and A.T. Wijayanta, “Performance of a simple custom air-water harvester using several pipe diameters as the condensation unit”, Proceedings of MIMSE, 102–112, 2022. https://doi.org/10.2991/978-94-6463-078-7_12

[7] Z. Djafar, J.A. Thufail, S. Nadila, D. Utamidewi, Mustofa, and W.H. Piarah, “Experimental study: Effect of refrigerant and inlet air flow rate on the productivity of atmospheric water generator”, International Journal of Heat and Technology, 43(1), 202–208, 2025.

[8] A. Suriatman, “Performance of water harvester with small pipe condenser unit at various inlet air velocities”, Thesis, University of Mataram, 2022.

[9] M. Mirmanto, M. Wirawan, and F. Sunaryo, “Performance of air water harvester machine with spiral condensing unit at various intake air velocities”, JP Heat and Mass Transfer, vol. 36, no. 1, 59-69, 2023.

[10] M. Mirmanto, N. Nurpatria, and J.K. Hendra, Effect of air intake temperatures on the air-water harvester performance, JOURNAL OF ENGINEERING SCIENCES (UKRINE), vol. 11, no.1, G1-G8, 2024.

[11] M. Mirmanto, R. Sutanto, and A. Saputra, “The effect of incoming air speed on the water mass produced in the air-water harvester machine with a power of 1 PK”, International Journal of Research in Engineering and Science (IJRES), vol. 13, no.4, 152-157, 2025.

[12] M. Mirmanto, M. Wirawan, I. Fathoni, “Improving water generator performance by using various evaporator pipe diameters”, Dinamika Teknik Mesin: Jurnal Keilmuan dan Terapan Teknik Mesin, vol. 16, no. 1, 70-75, 2026.

[13] A. Firdaus, “Analysis of air velocity effects on water production in a coil-type atmospheric water harvester”, Thesis, University of Mataram, 2022.

[14] M. Fauzan, “Performance evaluation of atmospheric water harvesting systems under varying airflow conditions”, Thesis, University of Mataram, 2022.

[15] M. Irhami, “Experimental study of heat transfer characteristics in water harvester machines”, Thesis, University of Mataram, 2023.

[16] S. Ardiansyah, “Performance of an air-water harvester machine with open and closed evaporators”, Thesis, University of Mataram, 2025.

[17] A. Faroni, “The effect of the diameter of the condenser unit pipe on the mass of water produced from the air-water harvester”, Thesis, University of Mataram, Indonesia, 2022.

[18] Y.A. Çengel, and M.A. Boles, “Thermodynamics: An engineering approach”, 8th ed., McGraw-Hill.

[19] Z.T. Handaru, “Effect of coil evaporator position on the performance of forced convection air–water harvester”, Thesis, University of Mataram, 2023.

[20] F.P. Incropera, D.P. DeWitt, T.L. Bergman, and A.S. Lavine, “Fundamentals of heat and mass transfer”, 6th ed., John Wiley & Sons, 2027.

[21] C.C. Wang, Y.M. Tsai, and D.C. Lu, “Refrigerant distribution in parallel evaporator systems and its impact on heat transfer performance”, International Journal of Refrigeration, vol. 66, 107–118, 2016. https://doi.org/10.1016/j.ijrefrig.2016.01.012