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Analysis Of Water Harvester Machine Performance Using Single-Sided Thermoelectric Cooling

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Abstract

This study addresses the urgent issue of global water scarcity, particularly in arid regions with limited access to conventional water sources. The performance of a water harvester equipped with single-sided thermoelectric cooling technology is evaluated to enhance water collection efficiency from the atmosphere. The primary objective of this research is to optimize the machine's performance by varying fan speeds and analyzing its impact on collected water volume. The methodology involves experiments conducted at three different fan speeds: 1000 RPM, 1500 RPM, and 2000 RPM, with each speed tested for three hours and data collected every 30 minutes. The observed variables include collected water volume, air temperature, and humidity. Results indicate that water collection efficiency increases with higher fan speeds, with 2000 RPM yielding the highest volume. However, efficiency declines after 90 minutes, mainly influenced by fluctuating external factors such as temperature and humidity. Additionally, increased fan speeds may result in higher energy consumption, which is a consideration for developing more energy-efficient machines. The study recommends further development to integrate automatic control systems capable of adjusting fan speeds based on environmental changes in temperature and humidity. The conclusion of this research is that thermoelectric cooling technology has significant potential for water harvesting, yet sustainable innovations are necessary for adaptation across diverse environmental conditions.

Keywords: water scarcity, water harvester, thermoelectric cooling, fan speed, environmental conditions

Abstrak

Penelitian ini mengangkat isu mendesak mengenai kelangkaan air global, terutama di wilayah beriklim kering yang memiliki keterbatasan akses terhadap sumber air konvensional. Teknologi pemanen air berbasis pendingin termoelektrik satu sisi dikaji dalam upaya meningkatkan efisiensi pengumpulan air dari udara. Tujuan utama dari penelitian ini adalah mengoptimalkan performa mesin dengan memvariasikan kecepatan kipas dan menganalisis dampaknya terhadap volume air yang terkumpul. Metode yang digunakan melibatkan eksperimen pada tiga tingkat kecepatan kipas, yaitu 1000 RPM, 1500 RPM, dan 2000 RPM, masing-masing diuji selama tiga jam dengan pengukuran data setiap 30 menit. Variabel yang diamati meliputi volume air yang terkumpul, suhu udara, dan kelembaban. Hasil penelitian menunjukkan bahwa efisiensi pengumpulan air meningkat seiring dengan peningkatan kecepatan kipas, di mana 2000 RPM menghasilkan volume tertinggi. Namun, efisiensi ini menurun setelah 90 menit, terutama dipengaruhi oleh kondisi eksternal seperti suhu dan kelembaban yang fluktuatif. Selain itu, peningkatan kecepatan kipas berpotensi meningkatkan konsumsi energi, yang perlu dipertimbangkan dalam pengembangan mesin yang lebih hemat energi. Penelitian ini menyarankan pengembangan lebih lanjut untuk mengintegrasikan sistem kontrol otomatis yang dapat menyesuaikan kecepatan kipas berdasarkan perubahan suhu dan kelembaban lingkungan. Simpulan dari penelitian ini adalah bahwa teknologi pendingin termoelektrik memiliki potensi yang signifikan dalam pemanenan air, namun perlu ada inovasi yang lebih berkelanjutan untuk adaptasi di berbagai kondisi lingkungan.

Kata Kunci: kelangkaan air, pemanen air, pendingin termoelektrik, kecepatan kipas, kondisi lingkungan

1. Introduction

The global water scarcity issue is becoming increasingly urgent, particularly in regions with arid climates and low rainfall. According to a report by the World Wildlife Fund (WWF), around 1.1 billion people worldwide lack access to clean water, and this number is expected to rise due to population growth and climate change [1]. Data from the United Nations (UN) indicates that by 2050, nearly 5 billion people will be living in areas with limited water supply, emphasizing the importance of innovation in water resource management [2]. This situation calls for technological innovation to address the challenge of providing clean water, especially in areas facing shortages of traditional water sources such as rivers and lakes [3].

One technology emerging as a potential solution is the water harvester, which can collect water from the air through the process of condensation. This technology is becoming increasingly relevant amid the growing risk of water shortages due to global climate change [4]. The machine enables water collection in regions experiencing shortages of traditional water sources. Air water harvesting has become the focus of several studies, as this method can be utilized in areas with limited access to surface or groundwater [5].

Such a water harvester would be very environment-dependent, and could only work efficiently in certain areas with the right temperature and humidity levels. Those surroundings then feed into how efficient condensation happens and, because of that, how much water is collected in reality [6]. Increased humidity, for example, usually leads to higher capacities of the machine in collecting water with an additional effect being that at colder temperatures the condensation process is slower because there is less moisture present [7]. It underscores the necessity for creative designs that enable better water harvesting, particularly in locations with harsh environmental conditions.

This machine is enabled with a cooling mechanism powered by thermoelectric technology. Working of thermoelectric: Here the water harvester cools air to the dew point, at which fresh droplets condense fast [8]. Thermoelectric cooling technology allows for higher energy efficiency relative to traditional cooling means with its ability to function within varied environmental conditions [9].

Several previous studies have demonstrated the success of using thermoelectric technology to improve the efficiency of water harvesters. For example, research conducted by Hooshmand Zaferani et al. (2021) found that employing this technology can enhance water collection efficiency by up to 15% compared to systems that do not use thermoelectric cooling technology [10]. In addition, research conducted by Ahmed and Nasir (2022) also supports these findings, demonstrating an increase in water collection capacity in dry climates through the optimization of thermoelectric cooling systems [11].

A study by Alenezi et al. (2023) explored how cooler temperatures can affect water harvesting, finding that colder conditions led to better efficiency in collecting water [8]. Thavalengal et al. (2023) added to this by showing that thermoelectric cooling, when applied at lower temperatures, improves water collection rates without causing a big increase in energy use. These insights point to a promising path for boosting the performance of water harvesters by refining cooling techniques [12].

This research aims to broaden the understanding of the impact of one-sided thermoelectric cooling technology on the performance of water harvesters. The primary focus is on evaluating how variations in fan speed affect the machine's efficiency in collecting water under different time conditions. Additionally, this study seeks to explore whether temperature and humidity settings can be further optimized to achieve more efficient outcomes in real-world scenarios.

The aim of this research is to analyze the performance of water harvesters equipped with one-sided thermoelectric cooling technology and to identify the most significant variables that influence water collection efficiency. It is hoped that this study will make a meaningful contribution to developing solutions for the global water shortage crisis.

2. Research Methodology

This research adopts an experimental approach to investigate the performance of a water harvester machine integrated with one-sided thermoelectric cooling under varied operational conditions. The core objective is to examine how different fan speeds (1000 RPM, 1500 RPM, and 2000 RPM) influence water collection over time. The experimentation at each fan speed lasts three hours, with data points collected every 30 minutes. By analyzing the correlation between fan speed and water output, this study provides insights into optimizing water collection efficiency through thermoelectric cooling.

In terms of location, the research was conducted at a private residence located at Jl. Amal Bakti No.8, Labuh Baru Timur, Payung Sekaki, Kota Pekanbaru, Riau. The experimental period commenced after the approval of the research proposal by the supervisory committee.

2.1 Tools and Materials

a. Water Harvester

The main equipment used is a water harvester, designed to extract moisture from ambient air via condensation.


Figure 1. Water Harvester Machine

b. Axial Fan
An axial fan is crucial in this setup, as it channels air into the water harvester to facilitate condensation. The fan speeds 1000 RPM, 1500 RPM, and 2000 RPM are tested to analyze their impact on water collection efficiency.


Figure 2. Axial Fan

c. Thermoelectric Cooler
The thermoelectric cooler is integrated into the system to reduce the air temperature, aiding the condensation process. This component plays a key role in optimizing water collection by facilitating the formation of water droplets.


Figure 3. Thermoelectric Cooler

d. Anemometer
To accurately measure airspeed within the system, an anemometer was employed. It provided air velocity data in m/s, which is critical for analyzing the fan's performance across varying speeds.


Figure 1. Anemometer

e. Thermometer
A thermometer was used to monitor the air temperature within the harvester, ensuring optimal conditions for condensation.


Figure 5. Thermometer

f. Condenser
The condenser further aids in the cooling and condensation processes, enhancing water output.

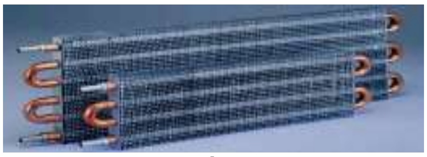
Figure 6. Condenser

g. Electric Drill and Other Basic Tools
For assembly purposes, an electric drill, screwdriver, and other tools were utilized to build and maintain the water harvester.

h. Water Collection Tank
A water collection tank was employed to store the condensed water. The volume of water collected was recorded during each testing phase.


Figure 7. Water Collection Tank

2.2 Procedure
The experiment was conducted as follows:
a. Initial Setup
All components were tested and calibrated to ensure proper functionality before data collection began.

b. Data Collection

Data was recorded at 30-minute intervals during each 3-hour session for all fan speeds. This involved measuring air temperature, humidity, airspeed, and the volume of water collected.

c. Analysis Techniques

Water production capacity was calculated based on the volume generated per hour. Each variable (fan speed, airspeed, temperature, and water output) was statistically analyzed to identify trends and optimize machine performance.

d. Data Processing

The collected data was processed using basic statistical methods to determine linear or non-linear relationships between the tested variables, focusing on identifying the optimal fan speed for water collection.

3. Result and Discussion

3.1 Research Result

The experiment involved evaluating the performance of the water harvester at three fan speed settings: 1000 RPM, 1500 RPM, and 2000 RPM. Data collection occurred at 30-minute intervals over a span of three hours, focusing on key measurements like the speed of the incoming and outgoing air, ambient temperature, humidity levels, and the amount of water gathered. The goal of the study was to explore how varying fan speeds influenced the machine's efficiency in collecting water.

Table 1. Harvester Machine Specifications

Water Harvester Machine Specifications	
Power	125 *watt*
Dimensions	42 cm x 30 cm x 22 cm
Fan Size	15 cm x 15 cm x 5 cm
Electric Current (Power Supply)	20,8 A
Voltage	AC 220V/DC 12V
Fan *Speed*	1, 2, 3
Thermoelectric TEC1-12705	5 A/DC

a. Test Results at 1000 RPM

At a fan speed of 1000 RPM, the volume of water collected increased in a linear pattern over the course of 180 minutes. In the first 30 minutes, 2.6 ml of water was gathered, and this volume continued to rise, reaching 17.3 ml by the end of the three-hour test. However, the rate of water collection per hour showed a decline in effectiveness after the first 90 minutes. This is evident from the drop in water production capacity from 5.7 ml/hour at the 120-minute mark to 5.6 ml/hour at 150 minutes, before stabilizing back at 5.7 ml/hour by the end of the test.

Table 2. Test Results at Speed 1 (1000 RPM)

Time (minutes)	Air Temperature (°C)	Air Humidity (%)	Incoming Air Speed (m/s)	Water Volume (ml)
30	26,1	75,9	3	2,6
60	25,7	75,3	3	5,5
90	25,5	74,9	3	8,2
120	24,6	74,6	3	11,4
150	24,3	74,7	3	14,1
180	24,2	74,4	3	17,3

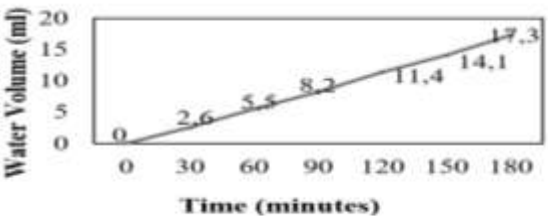

Figure 8. Graph of Time vs. Water Volume at 1000 RPM

b. Test Results at 1500 RPM

The results indicated that the volume of water collected had a greater effect by increasing the fan speed to 1500 RPM than at 1000 RPM. By the end of the test, 29.6 ml of water was collected in a period lasting two hours, having reached 6.4 ml in the first 30 minutes but showing no further significant increase afterward. Although the water volume scaled linearly with time, it became clear that efficiency decreased after the first 90 minutes. Between 90 and 120 minutes, the water production rate dropped from 10.4 ml/hour to 9.8 ml/hour by the end of the test.

Table 3. Test Results at Speed 2 (1500 RPM)

Time (minutes)	Air Temperature (°C)	Air Humidity (%)	Incoming Air Speed (m/s)	Water Volume (ml)
30	26,9	76	3,5	6,4
60	26,4	75,3	3,5	11,1
90	24,5	75,5	3,5	15,6
120	24,4	75,1	3,5	20,8
150	23,1	74,7	3,5	25,1
180	23,8	74,4	3,5	29,6

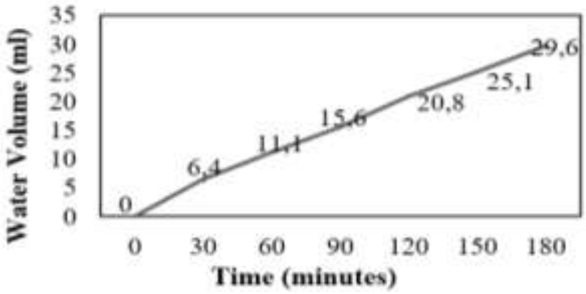

Figure 9. Graph of Time vs. Water Volume at 1500 RPM

c. Test Results at 2000 RPM

While at 2000 RPM, the output water volume had the highest percentage increase of all three speed variations. During the first 30 minutes, the volume increased to 6.5 ml and rose further with time until it finally reached 57.1 ml by the end of the test. There was also a higher water production capacity gain, reaching up to 19 ml/hour by the conclusion of the test. A similar trend was observed in water collection, with the efficiency decreasing after 90 minutes, although it remained higher than at lower speeds.

Table 4. Test Results at Speed 3 (2000 RPM)

Time (minutes)	Air Temperature (°C)	Air Humidity (%)	Incoming Air Speed (m/s)	Water Volume (ml)
30	26,3	75,9	4	6,5
60	25,6	75,4	4	16,7
90	25,4	74,8	4	26,6
120	24,1	74,5	4	37,4
150	24,6	74,1	4	47,2
180	23,9	73	4	57,1

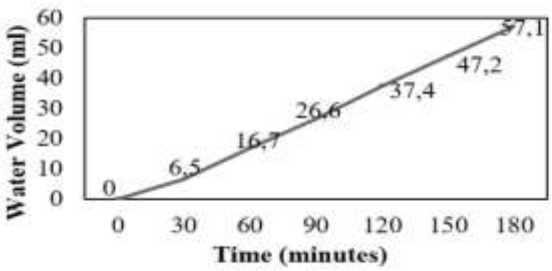

Figure 10. Graph of Time vs. Water Volume at 2000 RPM

The test results graph demonstrates that with each fan speed variation, the amount of water collected nearly doubled during the initial hours and then began to slow down. The most pronounced results were observed at 2000 RPM, where the volume of water gathered was significantly higher compared to the other two speeds. At 1000 RPM, the collected volume was just 17.3 ml, but it sharply increased to 57.1 ml at 2000 RPM.

3.2 Discussion

a) Water Collection Efficiency Based on Fan Speed

The research shows that a spike in fan speed has enormous implications on the amount of water being collected. At 2000 RPM, the water harvester was able to produce significantly more water than at 1000 RPM and 1500 RPM, with about a 1.5-fold higher rate. This can be easily explained by thermodynamics: when there is free airflow, greater amounts of water vapor in the atmosphere are able to condense into liquid water. These numbers are supported by Figure 9, where after 180 minutes, the collected water volume reached 57.1 ml at 2000 RPM, while it was only 17.3 ml at 1000 RPM. This finding is also consistent with the results of Jun Li et al., who demonstrated that airspeed affects the rate of water vapor condensation [7].

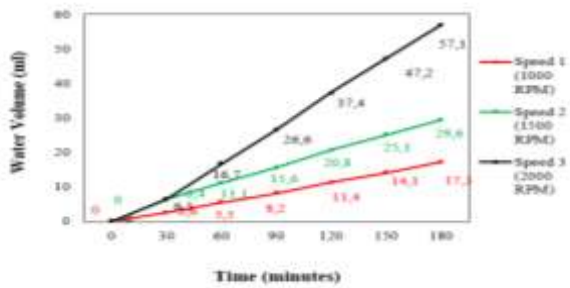

Figure 11. Effect of Fan Speed on Time and Water Volume

The improvement in effectiveness with the increase in fan speed diminishes after a certain period, as shown by the drop in the water production rate after 90 minutes. This condition could occur due to external factors such as changes in temperature and air humidity. As stated by Bai et al. (2024), environmental temperature and relative humidity are crucial factors in the evaporation and condensation rates within water harvesting systems [13]. At 2000 RPM, the water production rate increased sharply up to 120 minutes before starting to decline, likely due to the reduction of available water vapor in the air surrounding the machine [14].

When running at 1000 RPM, the volume of water collected was lower; however, the efficiency of the machine appeared to remain stable throughout the test (Figure 10). It is possible that lower speeds are more efficient under certain environmental conditions, such as higher humidity or colder air temperatures, which would facilitate the condensation process without requiring faster airflow. Research by Jarimi et al. (2020) indicates that under high humidity conditions, an increase in airflow does not necessarily lead to an increase in condensation efficiency [6].

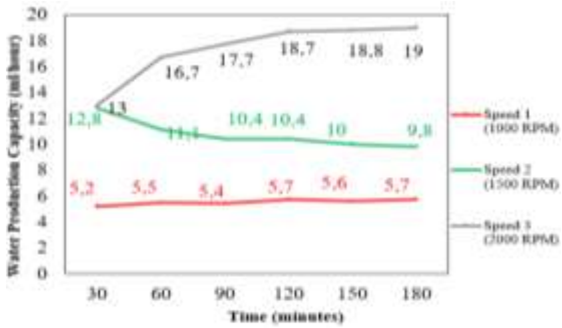

Figure 12. Effect of Fan Speed on Time and Water Production Capacity

More water was produced at 1500 RPM than at 1000 RPM, but an efficiency drop after 90 minutes also became apparent. This suggests that increasing fan speed can yield a larger volume of water collected, but there is a constraint in collection efficiency over time. This aligns with the findings of earlier research, where raising fan speed accelerated water collection but did not necessarily improve overall efficiency in the long term [15].

b) Analysis of Temperature and Humidity Factors

Water collection efficiency depends on temperature and humidity. As air moves through at higher speeds, it cools quickly, allowing more water vapor to condense. However, when environmental temperatures are too low at certain intervals, the condensation process may become less efficient. As seen in Figure 10, water production at 2000 RPM started to decline after 90 minutes, likely due to reduced water vapor in the air. Nusa (2015) demonstrated that in lower temperature conditions, the cooling rate can surpass the evaporation rate, leading to less water being condensed [16].

The air humidity is also responsible for the amount of water collected. The more water vapor in the air, and thus the higher the humidity, the more there is for the machine to condense. As shown in the test results over 180 minutes, at 2000 RPM, the machine produced more water because the faster airflow caused a higher condensation rate. However, at lower speeds, the collected water volume remained constant due to stable air humidity throughout the test. This finding is supported by Li (2023), who also found that high air humidity allows for a stable condensation rate even with slower airflow speeds [7].

The recent study by Jarimi et al. (2020) reported that different climatic conditions can affect condensation efficiency, which is crucial for the application of water harvesters in various environments [6]. Notably, at 1000 RPM, despite the smaller amount of water collected, the stability in water production suggests that under high humidity conditions, the water harvester system could still function efficiently without requiring high fan speeds. This is especially important in specific environments where the energy used to increase fan speed may not justify the increase in collected water volume.

c) Energy Implications and Machine Design

The more water is condensed, the higher the temperature of the air coming out at the top, and if the fan speed is increased too much, energy consumption rises while less water is collected. This research showed that 2000 RPM produced the most water but also consumed the most energy. Therefore, finding a balance between energy efficiency and water collection is crucial. Future water harvester development could include automatic settings that adjust fan speed based on surrounding temperature and humidity. A more sophisticated machine design, capable of automatically optimizing fan speed according to environmental conditions, could enhance water collection efficiency without significantly increasing energy consumption. This automatic control technology would enable the machine to function more effectively in varying environmental conditions, such as those common in dry climates.

4. Conclusion

In general, the study indicates that increasing fan speed on a water harvester machine results in more water being collected but also causes efficiency loss faster after a certain period. Temperature and humidity significantly affect the machine's performance, so fan speeds need to be adjusted according to environmental conditions. Further development of this machine could involve incorporating an automatic control system that adjusts fan speed based on temperature and humidity changes, improving water collection efficiency without significantly increasing energy consumption.

Along these lines, the present study serves as a foundation for advancing water harvester technology using thermoelectric cooling. Future research should focus on optimizing machine design to minimize energy consumption and enhance water collection efficiency across various environmental conditions.

References

[1] World Wildlife Fund, 2024. Water Scarcity. Available at https://www.worldwildlife.org/threats/water-scarcity/. [accessed 25 Juli 2024].

[2] UN News, 2021. Climate change, population increase fuel looming water crisis: WMO. (Updated 5 October 2021) Available at : https://news.un.org/en/story/2021/10/1102162 [accessed 25 Juli 2024].

[3] V. G. Gude., 2017. Desalination and water reuse to address global water scarcity, 16 (4), pp.591–609.

[4] M. A. Siddiqui, M. A. Azam, M. M. Khan, S. Iqbal, M. U. Khan, and Y. Raffat., 2023. Current trends on extraction of water from air: *an alternative solution to water supply*, 20 (1), pp.1053–1080.

[5] N. Asim *et al.*, 2021. Sorbent-based air water-harvesting systems: *progress, limitation, and consideration*. 20 (1), pp.257–279.

[6] H. Jarimi, R. Powell, and S. Riffat., 2020. Review of sustainable methods for atmospheric water harvesting, 15 (2), pp.253–276.

[7] H.-J. Li, L. Cheng, P. Sun, F.-F. Li, and J. Qiu., 2023. Potential Analysis of Atmospheric Water Harvesting Technologies from the Perspective of '*Trading-in Energy for Water'*, *Water*, 15 (5), pp.878

[8] A. Alenezi, H.-H. Jung, and Y. Alabaiadly., 2023. Experimental and Numerical Analysis of an Atmospheric Water Harvester Using a Thermoelectric Cooler, 14 (2).

[9] T. Xing *et al.*, 2021. High efficiency GeTe-based materials and modules for thermoelectric power generation, 14 (2), pp. 995–1003.

[10] S. Hooshmand Zaferani, M. Jafarian, D. Vashaee, and R. Ghomashchi., 2021. Thermal Management Systems and Waste Heat Recycling by Thermoelectric Generators—An Overview, *Energies*, 14 (18).

[11] B. K. I. Ahmed and A. W. Nasir., 2022. Significance of Thermoelectric Cooler Approach of Atmospheric Water Generator for Solving Fresh Water Scarcity BT - Intelligent Sustainable Systems, A. K. Nagar, D. S. Jat, G. Marín-Raventós, and D. K. Mishra, Eds., Singapore: Springer Nature Singapore, [accesed 17 Desember 2021] pp.377–383.

[12] M. S. Thavalengal et al., 2023. Progress and Prospects of Air Water Harvesting System for Remote Areas, 16 (6), pp.1-27.

[13] Q. Bai, W. Zhou, W. Cui, and Z. Qi., 2024. Research Progress on Hygroscopic Agents for Atmospheric Water Harvesting Systems, 17 (3), pp.722.

[14] A. Agrawal and A. Kumar., 2024. A comprehensive review of fresh water production from atmospheric air – techniques, challenges and opportunities. *Solar Energy*, 66 (2), pp.165–168.

[15] D. Kaya, F. Çanka Kılıç, and H. H. Öztürk., 2021. Energy Efficiency in Fans BT - Energy Management and Energy Efficiency in Industry: Practical Examples, pp. 419–425.

[16] I. Nusa., 2015. Teknologi Pendingin Evaporasi (Evaporate Cooling) Untuk Memperpanjang Umur Simpan Buah Dan Sayuran Segar, 19 (3), pp.281–288.