Research article

Design and Experimental Analysis of Atmospheric Water Generator Based on the Climatic Conditions of Manolo Fortich, Bukidnon

TAN JERICO D.*
Mindanao State University-Iligan Institute of Technology, Iligan City, Philippines
Email: jerico.tan@g.msuiit.edu.ph

ALBIENTO ELIZABETH EDAN M.
Mindanao State University-Iligan Institute of Technology, Iligan City, Philippines

Received 29 January 2022 Accepted 2 May 2022 (*Corresponding Author)

Abstract Most Filipinos living in remote rural and island communities rely on unsafe drinking water sources due to a lack of reliable water supply. With this, an atmospheric water generator (AWG) can become an alternative water source by condensing and collecting water vapour present in the air. However, previous research on the design of AWG devices was conducted outside the Philippines and most studies did not design the longitudinal profile of the fins and intake fan component of the device. This study designed the longitudinal fin profile of the fins and intake fan speed based on the climatic conditions of Manolo Fortich, Bukidnon and analysed the performance of the device by conducting a field experiment. The study designed the extended fins and varied the intake fan speed by conducting a parametric analysis using existing heat and mass transfer equations. The study then conducted a field experiment of the AWG device by placing the device in a secure open space. Results of the design showed that the 9 cm fin length was optimal for the device and that higher intake fan speed were more suitable for high relative humidity (RH) and high air temperature conditions. Results from the field experiment showed that higher water productivity was observed at higher RH level compared the lower RH levels. The study concludes that a longer length of copper fins and greater magnitude of intake fan speed does not necessarily translate to higher water productivity and that higher water production rates were observed during high RH levels.

Keywords atmospheric water generator, Peltier effect, thermoelectric couple

INTRODUCTION

Potable water is a necessity for us humans to live. However, most of the river systems in the Philippines face severe problems of pollution, which resulted in the higher cost of the supply of potable water throughout the country (Rola et al., 2015). One way to obtain water cheaply and sustainably is to produce water out of air through condensation by using an atmospheric water generator technology (AWG) with the use of thermoelectric couples (TEC).

AWGs are comprised of several components. The TEC is the main cooling unit which consists of a cold surface on one side and a hot surface on the other side when an electric current is passed thru the device. Copper fins are attached to the cold side to increase the surface area of the cold surface. A fan is installed to suck in air into the device for air to come in contact with the cold copper surface making the water vapor condense in these areas. Only around 1% of the carbon dioxide (CO_2) present in the air will dissolve in condensed water vapor to form carbonic acid (H_2CO_3) making the water acidic with a pH as low as 5.5 (Bauer et al., 1980). With this, copper pitting due to carbonic acid is less likely to occur at a lower PH of water (Taxen, 2002). The study did not delve deeper in the extent of the effect of carbonic acid on the copper fins. The hot side is usually installed with an aluminum heat sink to dissipate the heat produced by the TEC. However, little work has been done on the design of two major components of the AWG namely the cold side copper fins and the intake fan and most of the studies were designed outside the Philippines. In this study, the length of copper fins was optimized and the intake fan speed was varied based on Philippine climatic conditions and analyzed its performance in an actual field experiment.

OBJECTIVE

The main objective of this study is to optimize the design of an AWG device based on the climatic conditions of Manolo Fortich, Bukidnon. Specifically, the study will optimize the length of copper fins, identify the appropriate intake air velocity considering a maximum air velocity, fabricate the AWG prototype, and analyze the field test results of the AWG device.

METHODOLOGY

Optimization of Length of Copper Fins

The study initially acquired climatic data for Manolo Fortich, Bukidnon. The average values of the lowest, median and highest temperature and relative humidity were computed and determined the dewpoint temperatures using these values. The study then considered four different lengths of copper fins namely 8 cm, 9 cm, 10 cm and 11 cm. To maximize the amount of water generated in the device, all the surface area along the length of the copper fin should be less than the dewpoint temperature for maximum water condensation. Hence, the study performed a parametric analysis in solving the temperature distribution along the fins, using Equation 1, by using different fins lengths and different climatic conditions. The temperature distribution equation was emulated from the study of Shourideh et al. (2018) and Kilic and Onat (1981). The lengths of fin 8 cm, 9 cm, 10 cm and 11 cm that has a temperature distribution below the dewpoint at different climatic conditions were chosen as the optimized length of copper fins.

$$\frac{d^2T}{dx^2} = m^2\left[(T - T_a) - \frac{h_m h^*_{fg}}{hR_vT_a}(P_{v,T_a} - P_{v,T})\right] \quad (1)$$

Where m is fin parameter, T local fin temperature (K), T_a temperature of the surrounding air (K), h_m mass transfer coefficient (m/s), h_{fg*} modified latent heat of vaporization (J/kg), h convective heat transfer (W/m^2-K), R_v ideal gas constant (J/kg-K), T_a temperature of the surrounding air (K), $P_{v,Ta}$ partial pressure of water vapour in the surrounding air, and $P_{v,T}$ partial pressure of water vapour in the fin surface.

Also, the boundary conditions for Equation 1 were shown in Equation 2 and Equation 3.

$$T(L_f) = T_0 \quad (2)$$

$$\left(\frac{dT}{dx}\right)_0 = 0 \quad (3)$$

Where L_f is length of fins (m) and T_0 initial cold side temperature of TEC (K).

Variation of Intake Air Velocity

The study also conducted a parametric analysis to compute the theoretical water generation rate by using different values of air velocity considering a maximum velocity of 4 m/s at different climatic conditions. The study utilized the equation shown in Equation 4 to compute the theoretical water generation rate. There were five cases of combinations of temperature and RH used in the analysis. The intake air velocity that gave the maximum water generation rate was chosen as the appropriate intake air velocity at that certain climatic condition.

$$V = \frac{2NbL_f m_w}{\rho_l} \quad (4)$$

Where V is water generation rate (m^3/s), ρ_l the density of water (kg/m^3) and N number of fins attached to the TEC.

RESULTS AND DISCUSSION

Optimized Length of Copper Fins

Parametric analysis for the temperature distribution of the 8 cm, 9 cm, 10 cm and 11 cm lengths of copper fins for different climatic conditions were computed. Fig. 1 shows the results of the temperature distribution of each of the copper fin lengths. It can be observed in Fig. 1 (b) that the 10cm and 11cm fin lengths exceeded the dewpoint temperature at 80% percent of its length. This meant that the surface temperature beyond this point was higher compared to the dewpoint temperature at that climatic condition. Hence, the water does not condense in these regions and the copper fins can be considered as partially wet fins under these conditions since not all of its surface area can condense water.

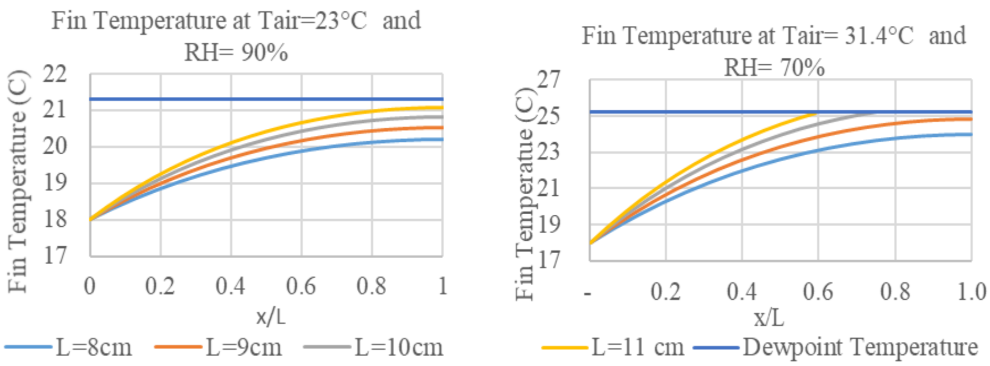

Fig. 1 Fin temperature distribution of different fin lengths at (a) T_a=23 C and RH =90%, (b) T_a=31.4 C and RH=70%

On the other hand, it can be seen in Fig. 2 that the 9 cm fin length did not reach the dewpoint temperature in all cases of climatic conditions. This meant that all the surface area of the 9 cm length copper fins can condense water vapor. Hence, the optimum length of the copper fins that was also incorporated in the design of the AWG was the 9cm length.

Variation of Intake Air Velocity

Table 1 presents the cases used in the analysis with different ambient air temperatures and variable RH levels.

Table 1 Summary of cases of temperature and RH used in the analysis

Case No.	T_a (ºC)	RH 1 (%)	RH 2 (%)	RH 3 (%)	RH 4 (%)
1	23.00	80.00	85.00	90.00	-
2	25.00	75.00	80.00	85.00	90.00
3	29.00	75.00	80.00	85.00	90.00
4	31.00	75.00	80.00	85.00	90.00

By applying these cases in the computation along with different variations of intake air velocity considering a maximum velocity of 4 m/s, the theoretical water generation rate was obtained and the results were shown in Fig. 2. It can be observed from the results that increasing the air velocity generally increases the water generation rate for most of the cases presented.

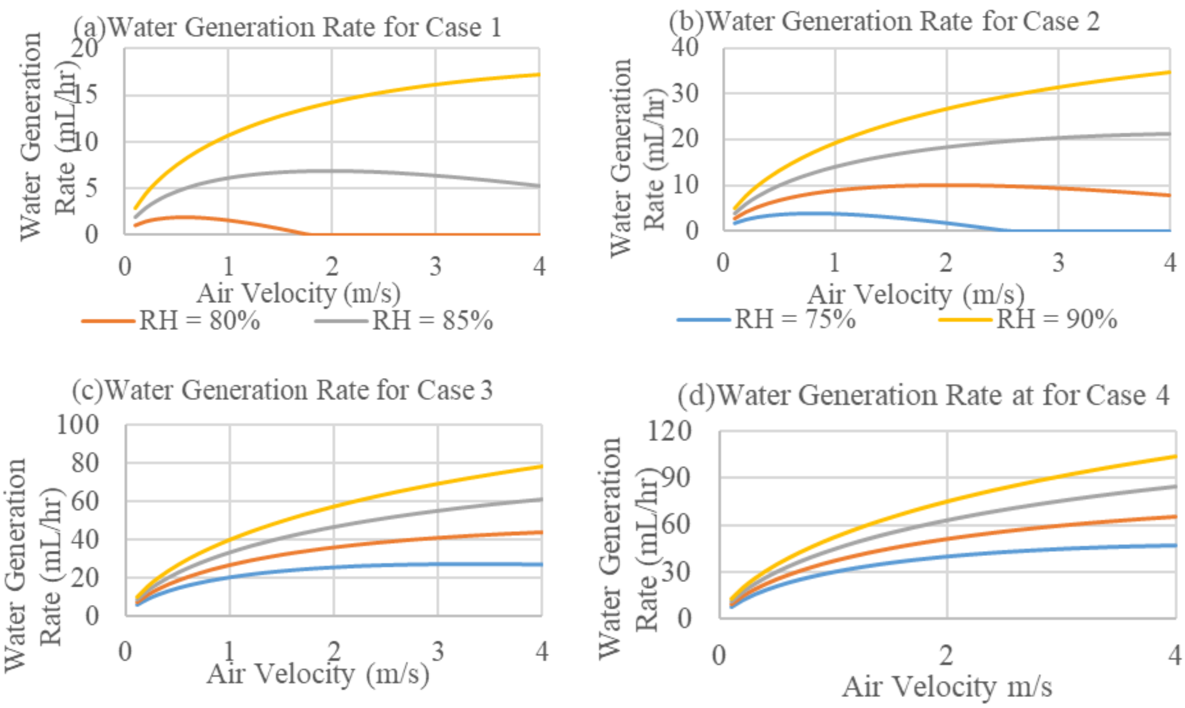

Fig. 2 Theoretical Water Generation Rate at different Air Velocities for (a) Case 1, (b) Case 2, (c) Case 3, (d) Case 4, and (e) Case 5

For Case 1 and Case 2, there was low ambient air temperature paired with low RH levels. It can be observed in Fig. 2 (a) and (b) that between RH of 75% to 80%, the water generation rate increased initially when the air velocity was also increased but then decreased at higher magnitudes of air velocity. Hence, the air velocity of the fans can be adjusted at peak water generation rate when the AWG device is subjected to low relative humidity such as in Case 1 and Case 2.

For Case 3 and Case 4, the increase in air velocity also increases the of water generation rate. For this case, the increase in the value of the mass transfer coefficient resulting from the increase in air velocity outweighed the decrease in the difference between the partial pressure of the surrounding air and partial pressure at the fin surface.

Based from the results shown in Fig. 2, Table 2 summarizes the appropriate intake air velocity at different climatic conditions. The values indicated in Table 2 were then incorporated into the design of the AWG in which the air velocity varied depending on the climatic conditions.

Table 2 Summary of appropriate air velocity at different climatic conditions

Relative humidity	Intake air velocity (m/s)			
	23°C ≤ 24°C	24°C ≤ 26°C	26°C ≤ 28°C	28°C ≤ Ta
75%<80%	0.00	0.20	2.00	4.00
80%<85%	0.60	2.00	4.00	4.00
85%<90%	2.00	4.00	4.00	4.00
90% ≤ 100%	4.00	4.00	4.00	4.00

Construction and Experimental Analysis of the Device

The study utilized the 9 cm copper fin length and the magnitudes of variable intake air velocity in the design of the AWG device. Figure 3 shows the blow-up figure of the AWG prototype.

The AWG device was continuously operated for 30 days in a secure open space located at Manolo Fortich, Bukidnon for the experimental analysis. The testing area for the field test was located in the backyard of a residential lot located in a rural community at Manolo Fortich, Bukidnon. The period of testing was between September to October 2021 and the experimental setup is shown in Fig. 3b. The average hourly RH, and the ambient air temperature were shown in Fig. 4 and the average hourly water collection was shown in Fig. 5.

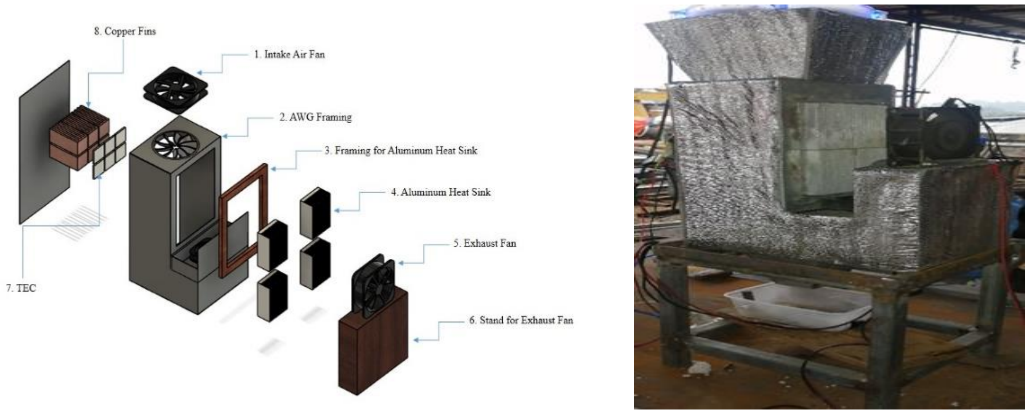

Fig. 3 Blow-up picture of the AWG Device with its corresponding parts (a) and finished product and experimental setup (b)

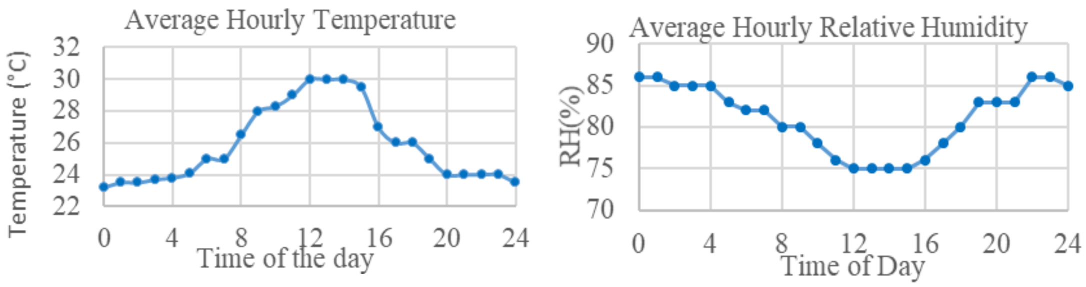

Fig. 4 Average hourly ambient air temperature and relative humidity

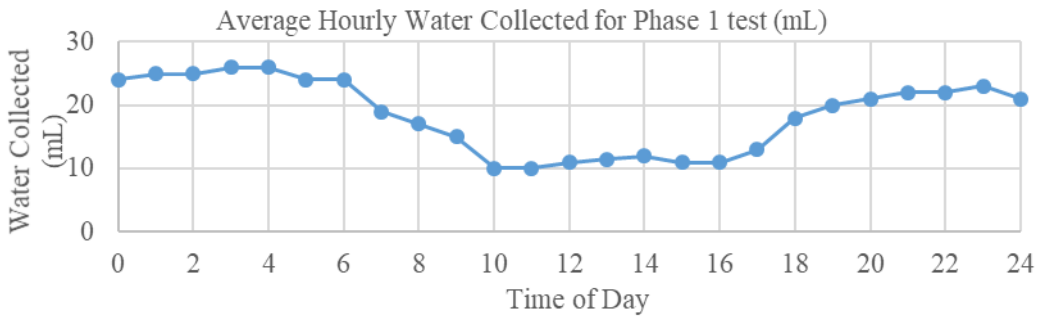

Fig. 5 Average hourly water collection for the AWG device

It can be seen in Fig. 5 that the highest water collection rate of the AWG was during nighttime since there were high RH levels paired with low surrounding temperatures. Overall, the highest recorded amount of water collected in a day was 526 mL. Table 3 shows the comparison between the outputs of this study compared to past literature.

Table 3 Comparison of water collected per day to past literatures

Researcher	Location	Water collected (mL/day)
Joshi et al. (2017)	India	480
Liu et al. (2017)	China	525
Present work	Philippines	526

CONCLUSION

The cold side fin length and air velocity are two important features of an AWG device that are needed to be designed to improve the efficiency and water generation rate. The study observed that while increasing the length of copper fins increases the cooling surface area, making the fin length excessively longer does not positively impact the water generation rate of the AWG. Longer fin lengths will develop dry regions along their length thus becoming inefficient.

Finally, the results of this study showed that there was an ideal air velocity at every climatic condition to harness the maximum water generation rate for the AWG device. Low air velocities were assigned to low surrounding temperature with low relative humidity conditions while high air velocities were designated for high surrounding temperature and high relative humidity conditions. The highest amount of water collected in a day was 526mL.

ACKNOWLEDGEMENTS

The author would like to acknowledge the Engineering Research and Development for Technology (ERDT) for funding this research and the Mindanao State University-Iligan Institute of Technology for supporting this research.

REFERENCES

Hafner, S. 2018. Re: How much CO2/DIC dissolves in water vapor condensate under normal atmospheric conditions? Retrieved from https://www.researchgate.net/post/How-much-CO2-DIC-dissolves-in-water-vapor-condensate-under-normal-atmospheric-conditions/5a75cecf615e27bab3589949/citation/download

Joshi, V., Joshi, S.V., Kothari, A.H., Mahajan, D.M., Chaudhari, B.M. and Sant, D.K. 2017. Experimental investigations on a portable freshwater generator using a thermoelectric cooler. Energy Procedia, 109, 161-166, Retrieved from DOI http://doi: 10.1016/j.egypro.2017.03.085

Kilic, A. and Onat, K. 1981. The optimum shape for convecting rectangular fins when condensation occurs. Warme - und Stoffubetragung, 15, 125-133, Retrieved from DOI https://doi.org/10.1007/BF01002408

Liu, S., He, W., Hu, D., Lv, S., Chen, D., Wu, X., Xu, F. and Li, S. 2017. Experimental analysis of a portable atmospheric water generator by thermoelectric cooling method. Energy Procedia, 142, 1609-1614, Retrieved from DOI https://doi.org/10.1016/j.egypro.2017.12.538

Rola, C.A., Pulhin, M.J., Tabios, Q.G., Lizada, C.J. and Dayo, F.M. 2015. Challenges of water governance in the Philippines. Philippine Journal of Science, 144 (2), 197-208, Retrieved from https://philjournalsci.dost.gov.ph/images/pdf/pjspdf/vol144no2/pdf/challenges_of_water_governance_in_the_Phils_FinalCopy_05_April_2016.pdf

Shourideh, H.A., Ajram, B.W., Lami, A.J., Haggag, S. and Mansouri, A. 2018. A comprehensive study of an atmospheric water generator using peltier effect. Thermal Science and Engineering Progress, 6, 14-26, Retrieved from DOI https://doi.org/10.1016/j.tsep.2018.02.015