Performance and Limitations of Atmospheric Water Generation Heat Pumps

Farshid BAGHERI, Majid BAHRAMI*
Simon Fraser University, School of Mechatronic Systems Engineering, *Laboratory for Alternative Energy Conversion* (LAEC), Surrey, BC, Canada
*Corresponding Author (Tel.: +1 (778) 782-8538; Email: mbahrami@sfu.ca)

ABSTRACT

In this paper performance and limitations of conventional atmospheric water generator (AWG) systems are experimentally investigated. A new experimental setup and test procedure are developed to measure the water harvesting rate and input electrical power of several residential-size AWGs from different manufacturers. The setup is equipped with an environmental chamber to mimic all climatic conditions in our lab and to obtain performance characteristics of AWG systems. The results show the range of water harvesting rate, energy intensity (1.02 kWh/L for warm and humid to 6.23 kWh/L for cold and humid climates), and limitations of the conventional AWG that can be used as a platform for development of higher efficiency heat pumps for atmospheric water harvesting in future.

1. INTRODUCTION

Over the 20th century and into the 21st century, the global population has increased by 300%, while water consumption has increased by 600% [1]. Freshwater is becoming a scarce commodity as climate change and man-made pollutants enter the water system. The United Nations has predicted that 48 countries will experience water stress or scarcity by 2025 [2]. Four billion people in the world face at least one month of water scarcity every year [3]. The water crisis will soon turn into food crisis in many areas of the world. With an estimated 12,800 trillion liters of renewable water available in the atmosphere, atmospheric water harvesting (generation) can be a viable solution to address some of the global needs for freshwater, especially where saline/brackish water is not available [4]. A conventional atmospheric water generator (AWG) is a heat pump that condensates humidity from air by cooling it below its dew point temperature. The literature lacks critical and independent investigation into realistic performance, functionality, and limitations of currently available AWG systems. As such, this study is focused on evaluating the performance of commercially available AWGs under various climatic conditions. A new experimental setup is designed and built in our lab and the performance and limitations of the existing AWGs are thoroughly investigated.

2. EXPERIMENTATION, RESULTS, AND DISCUSSION

2.1 Experimental Setup

A test-bed is custom-built to study the effect of climatic conditions on water harvesting rate and performance of commercially available AWG systems. The test-bed is equipped with a large environmental chamber (Espec, model EPX-4H Platinous) to provide the inlet air stream with a wide range of desired temperature (T) and relative humidity (RH) to mimic ambient conditions. A schematic of the test-bed is shown in Fig. 1. The test-bed is equipped with several Rotronic temperature and humidity sensors (model HC2-S3 with accuracy of ±0.1 °C and ±0.5% RH), air flow measurement (TSI anemometer vane model 5725) with accuracy of ±1.0%, and Fluke 902 clamp meter with accuracy of 2.0% for input electric power measurements.

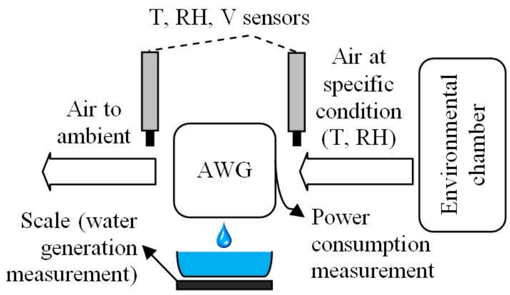

Figure 1: Schematic of testing facility.

Table 1: Sample performance test results for AWG #1

Test Conditions	T (°C)	RH (%)	ω (gr/kg)	$T_{dewpoint}$ (°C)	Water generation (L/h)	Energy consumption (kWh/L)	Energy costs* (₡/L)
Warm, humid (Florida Summer)	30	62	16.6	21.9	0.65	1.21	13.6
Mild, humid (Florida Spring)	20	75	11.0	15.5	0.48	1.49	16.8
Cold, humid (British Columbia Winter)	6	80	4.6	2.8	0.0	-	-
Warm, dry (Arizona Summer)	32	20	5.9	6.3	0.14	5.60	63.1
Mild, dry (Colorado Summer)	21	45	6.9	8.6	0.25	2.79	31.4
Cold, dry (Colorado Spring)	6	57	3.3	-1.6	0.0	-	-
Mild (California Summer)	25	50	9.9	13.9	0.29	2.52	28.4

* Energy cost is calculated based on BC-Hydro tariffs in Vancouver, BC, Canada as ₡11.27/kWh.

The data were measured every 30 seconds using a National Instrument data acquisition system (DAQ). In addition, the amount of water generation is measured every 15 minutes, using a scale (Precision Weighing Balances model AEP-1500G) with accuracy of ±0.02g. Using the test-bed, a few commercially available residential size AWGs are tested under a wide range of climatic conditions listed in Table 1 and the results are presented and discussed. Due to lack of a performance rating standard in the literature for AWGs, a new testing procedure is developed and followed in this study. A variety of general specifications and guidelines for performance rating of heat pumps is adopted from ANSI/AHRI Standard 210/240, ASHRAE Standard 16-2016, and ANSI/ASHRAE Standard 128-2011. For each test, the measurements are performed for 5 hours under steady-state conditions. All the tests are repeated 3 times to assure reproducibility of the acquired data.

2.2 Results and Discussion

The main goal of this study is to investigate the performance and limitations of commercially available AWG systems under the specific testing conditions listed in Table 1. As such, three residential-size AWGs (1500 W power or less) manufactured in the United States, Canada, and China are purchased and tested using the built test-bed per the testing procedure described in Section 2.1. These conditions are assumed based on average monthly data for different cities in North America, which can be expanded to similar climates around the world. An uncertainty analysis of the measured data shows an accuracy of ±0.01 kg/h for water generation and ±0.03 kWh for energy consumption. Analyzing the variation of water harvesting and energy consumption rates shows that neither T nor RH is a dominating factor alone in determining the performance of AWGs; however, the water content (humidity ratio, ω) or dew point temperature ($T_{dewpoint}$) plays a key role. To better demonstrate of the simultaneous effects of psychometric parameters on water harvesting rate, Fig. 2 is prepared in which larger bubbles indicate a higher harvesting rate over T, ω, (and/or $T_{dewpoint}$) range. As intuitively expected, water harvesting rates increases - while energy consumption per liter of water decreases- in areas with relatively low T and high ω or $T_{dewpoint}$. The dashed line in Fig. 2 demarcates the RH of 100% for atmospheric condition under which the maximum yield in water harvesting rate can be achieved. Noteworthy is another limitation for conventional AWG systems, which is the frost formation on the cooling coil (evaporator) for low inlet temperature and humidity climates. Based on our experiments, the existing AWG technology fails to operate in cold and dry conditions (T < ~6°C and RH < ~75%; ≈ $T_{dewpoint}$ < 2°C). Also, as shown in Table 1, cost of water harvesting increases as T increases or ω (consequently $T_{dewpoint}$) decreases.

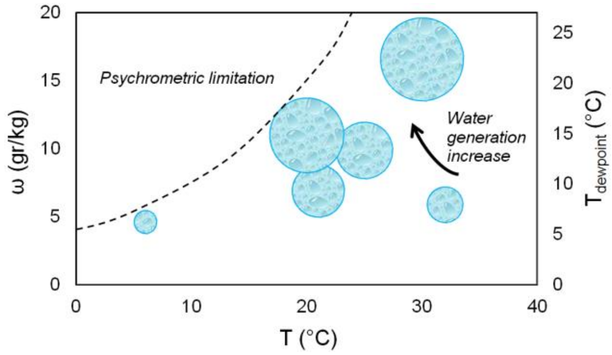

Figure 2: Water generation intensity vs. temperature (T), water content (ω), and $T_{dewpoint}$ (a larger bubble represents a larger water generation rate).

6. CONCLUSIONS

This study was focused on experimental performance investigation of commercially available AWG systems. A test-bed was built, which included: an environmental chamber and variety of sensors. Three residential-size AWGs were systematically tested under a variety of climatic conditions. The results showed that the water harvesting yield enhanced by simultaneous increase of ω or $T_{dewpoint}$ and decrease of temperature. The average water generation rate for residential-size AWGS (1,500 W power or less) varied in the range of 0.05 L/h for cold and humid to 0.65 L/h for warm and humid climates. The average energy consumption also changed from 1.02 kWh/L for warm and humid to 6.23 kWh/L for cold and humid climates. The results showed that the efficient functionality of existing AWG technology was limited to warm and humid climates. Also, due to significant hourly, daily, and seasonal variations of T and RH, a year round efficient operation of AWG was not possible in most geographical locations. A criterion of $T_{dewpoint}$ > 2°C was obtained as a minimum requirement of climatic condition for feasible atmospheric water generation.

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