EXPERIMENTAL STUDY OF A SOLAR-POWERED ATMOSPHERIC WATER GENERATOR

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Abstract

Drinking water availability is a major trouble in some regions in Libya because of the lack of water sources. The atmospheric water generator (AWG) is one of the alternative techniques for freshwater recuperation from the atmosphere, which condensed the moisture content of water vapor from the air directly. This paper affords an experimental study of AWG in Libyan climate conditions. In this study, a transportable AWG was experimentally studied. The effect of varied humidity, inlet airflow, and temperature, on AWG productivity and the energy required. The amount of generated water increases with the increase in temperature, humidity, and inlet airflow, reaching its peak (16.9 ml/(m$^3$ of air)) at 32.9 °C and 49% humidity, and it’s lowest value (6.85 ml/(m$^3$ of air)) at 29.5°C and 55% humidity. The maximum production efficiency of AWG was 93.430% at temperature 32.9 °C, humidity 49%, airflow 76.392 m$^3$/hr, and 1048.5 Watt.

Keywords: Air, atmospheric water generator, dew point, humidity.

المملوكة: نولدات المياه من الهواء عمل بالطاقة الشمسية

عبدالفتاح أبو القاسم المريض & فضل مصطفى العنابي

ملخص:

تعتبر مشكلة مياه الشرب أحد أكبر المشاكل في بعض مناطق ليبيا وذلك بسبب نقص مصادرها. اخذ اهم الطرق البديلة لتوفر المياه في الوقت الحاضر هي مولدات المياه التي تقوم بتكتشف نخار الماء من الهواء مباشرة. تقدم هذه الورقة دراسة تجريبية لمولد المياه تحت الظروف المناخية الليبية. تم تنفيذ دراسة تأثير كلاً من الرطوبة ، درجة حرارة الجو و معدل تدفق الهواء على إنتاجية الجهاز و معدل استهلاك الطاقة. حسب النتائج المتحصل عليها ، زادت كمية المياه المنتجة مع زيادة درجة الحرارة والرطوبة و معدل تدفق الهواء الداخل للجهاز ، حيث بلغت أكبر قيمة لها عند درجة حرارة 32.9°C و رطوبة نسبة 49% قيمته (16.9 ml/(m$^3$ of air)) و أقل قيمة عند درجة حرارة 29.5°C و رطوبة نسبة 55% بلغت (6.85 ml/(m$^3$ of air)). كانت أقصى كفاءة 93.430% عند درجة الحرارة 32.9 °C ، الرطوبة 49% ، معدل تدفق الهواء 76.392 m$^3$/h و معدل استهلاك للطاقة 1048.5 Watt.
1. INTRODUCTION

Because the burning of fossil fuels has produced significant air pollution problems and has also led in global warming, there is a need for clean, renewable energy sources to fulfill rising energy needs [1]. Libya is an oil-rich nation with around 90% of its land area located in the Sahara desert, making it a potential country in terms of alternative energy sources due to its location in the solar belt region with an optimum direct sun radiation level [2]. This solar energy resource could be turned into many types of energy, such as heat and electricity.

There are two major issues in rural areas in Libya: the first problem is shortage of drinking water in summer and the second problem is the scarcity of electricity energy. On 1 February 2021–UNICEF communicates worry over the decaying WASH circumstance in Libya. Over 4 million individuals, including 1.5 million children, will confront inevitable water issues if quick arrangements are not found and executed [3].

Water demand will increase by 55% by the year 2050 and that according to the OECD (Environmental outlook 2050). The major users will be BRICS (Brazil, Russia, India, Indonesia, China, South Africa) and developing countries with a 700% and 400% increase. Figure (1) represents the major needs come from the growth in the domestic, manufacturing, and power sector, combined with the increase of population, expected to be up to 33% focused in developing countries. [4].

![Figure (1) Global water demand in 2000 and 2050](image)

The amount of renewable water in the atmosphere is more than $12.9 \times 10^{12}$ m$^3$, this amount of renewable water is more than the total amount of fresh water in wetlands and rivers [5].
Many studies showed that AWG technology is the promising solution to those regions who lack access to proper infrastructure and economic resources of water extraction.

The desalination plants need a lot of energy (fossil fuel) and result of that is large footprint of carbon. In many regions that has a high solar radiation incidence, it's useful to couple technology of water extraction with solar resource.

There are different ways to extract water molecules from the atmosphere, but they have the same main idea based on the phase change from vapor to liquid.

This study investigates techniques. Atmospheric water generation using dehumidification techniques. This technology needs a less energy and this system can be used to generate water in any location using external energy resource or renewable energy resource[6].

The Atmospheric Water Generator (AWG) is one of the proposed techniques to solve this problem by condensing water vapor from the air. In case of the lack of electrical energy, the use of solar-powered AWG based on traditional compression refrigeration method is very suitable to apply in these conditions.

The compression refrigeration method uses a circulating refrigerant as medium. The refrigerant absorbs the heat from location and rejects it to the surrounding.

The conventional compression refrigeration system is one of the alternative methods for freshwater recovery from the atmosphere, and it can provide fresh drinking water by withdrawing water from saturated atmospheric air through the Cooling condensation mechanism [8]. In a cooling condensation-based atmospheric water generator, a compressor circulates the refrigerant into a condenser and an evaporator loop, cooling the surrounding air to dew point and causing vapor to condense[7]. The AWG performance depend on ambient air temperature, relative humidity and air flow rate. So, when the relative humidity and temperature rise the AWG operates more effectively, but when the humidity falls below 30% the AWG will not work efficiently [9].

2. METHODOLOGY

2.1 Experimental Setup

As seen in Fig.,(2) the refrigerant compressed in the compressor circulates through a condenser where turns into liquid and rejects the heat, then the refrigerant proceeds to capillary tube where expands, losing pressure and heat. The refrigerant leaves the capillary
tube in cold and liquid state and enters the evaporator, where it absorbs the heat which turns it to gas. The gas then pushed back into the compressor where the cycle starts again.

The ambient air enters the heat exchanger through channel (0.44 x 0.08m) at point (1) and flows around the aluminum pipes. The heat exchanger begins to chill the air to the dew point of the vapour, and numerous droplets of condensed water form as a result.

The condensed droplets of water begin to grow and fall outside the heat exchanger in the holding tank. A variable-speed fan (3) draws air from the heat exchanger and pushes it over the evaporator coil, where it cools again. This causes vapour to condense by reducing the air temperature of the vapour, resulting in many droplets of condensed water, which increased and ultimately dropped outside in the holding graduated cylinder.

Cooled air leaves the evaporator and enters the aluminum pipes (4) of the heat exchanger, where heat exchange begins with air entering the heat exchanger. The heat exchanger diagram is shown in Figure (3).

Figure (2) The diagram of structure of prototype.
2.2 Technical information of Solar system

The solar system designed for running for 10 hours/day

Table 1: Solar system specification

<table>
<thead>
<tr>
<th>PV Panels</th>
<th>Batteries</th>
<th>Inverters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers 4 Panels</td>
<td>Numbers 2</td>
<td>Capacity 3kw</td>
</tr>
<tr>
<td>Capacity 450 Watt</td>
<td>Capacity 100 AH</td>
<td>Type hybrid 48V</td>
</tr>
<tr>
<td>Company name: Trina Solar.</td>
<td>Company name: JYC</td>
<td>Company name: Sumry</td>
</tr>
</tbody>
</table>

2.3 Test Procedure

The tests were carried out between July 8th and July 16th, 2021 in Surman city 22 km away from the sea at coordinates (32.607231,12.502364). Monitoring devices were used, such as a clamp type multimeter to measure current and voltage, an anemometer for measuring the velocity of airflow at the intake and outlet, a thermocouple to measure airflow temperature, and a hygrograph to measure airflow humidity. Figure (2) shows the testing positions for temperature, airflow rate, and relative humidity. The measured data and generated water were recorded once every hour. The specs of experimental apparatuses used are defined in Table 2.

In Figure (2):

- At the point (1) to measure
  - The velocity of the air enters the heat exchanger, m/s.
2. The humidity of inlet air, %
3. The temperature of the inlet air, °C

- At the Points (2)
The temperature of the air enters the heat exchanger, °C
- At the point (3)
The temperature of the air enters the evaporator, °C
- At the point (4)
The average temperature of the air as it exits the heat exchanger, °C.

<table>
<thead>
<tr>
<th>Apparatus</th>
<th>Unit</th>
<th>Accuracy</th>
<th>Range</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clamp meter</td>
<td>A V</td>
<td>±(2.5%+15d)</td>
<td>400/600</td>
<td>Current and voltage testing</td>
</tr>
<tr>
<td>Anemometer</td>
<td>m/s</td>
<td>±0.0015</td>
<td>0.4-30.0</td>
<td>Air flow speed testing</td>
</tr>
<tr>
<td>Thermocouple</td>
<td>c</td>
<td>±0.1</td>
<td>-200 to1300</td>
<td>Temperature testing</td>
</tr>
<tr>
<td>Hygrograph</td>
<td>%</td>
<td>±3</td>
<td>0–99</td>
<td>Air humidity testing</td>
</tr>
<tr>
<td>Graduated cylinder</td>
<td>ml</td>
<td>±5</td>
<td>50-500</td>
<td>Water generated testing</td>
</tr>
</tbody>
</table>

**Table 2 : The specifications of experimental apparatuses used.**

2.4 Amount of water in the air for various humidity and temperature Values ($\dot{m}_{max}$)

The maximum amount of water ($\dot{m}_{max}$): it describes the maximum amount of water in the air as a function of air temperature and relative humidity.

The Approximate equation (1) for the maximum amount of water vapor in the air was obtained from moist air tables:

$$\dot{m}_{max} = (4.8 + 0.344 \times T_{in} + 9.52 \times 10^{-4} \times T_{in}^2 + 1.9 \times 10^{-4} \times T_{in}^3 + 1.835 \times 10^{-6} \times T_{in}^4) \times R \times h_{in} \times g/m^3 \ldots \ldots \ldots \ldots \ldots (1)$$

Where
2.5 Dew point temperature calculation

Dew-point temperature \(T_d\): is the temperature at which humidity in the air starts condensing at the same rate at which it is evaporating at a given constant barometric pressure.

The dew point is the saturation temperature for water in air and it is associated with relative humidity. A high relative humidity implies that the dew point is closer to the current air temperature. Relative humidity of 100% indicates the dew point is equal to the current temperature and that the air is maximally saturated. When the moisture content remains constant and temperature increases, relative humidity decreases [10].

\[
T_d = -26.44 + 0.757 \cdot T_{in} + 45.4862 \cdot R_{h_{in}} - 8.12424 \cdot 10^{-5} \cdot T_{in}^2 - 20.257 \cdot R_{h_{in}}^2 + 0.278 \cdot T_{in} \cdot R_{h_{in}} \quad \text{..... (2)}
\]

Where \(T_d\) represents the dew point, °C

3. EXPERIMENTAL RESULTS

Figure (4) shows the effect of air inlet temperature on water amount. The y-axis represents the water amount in \(ml/m^3\) air and x-axis represents the temperature of the inlet in °C at 39% constant humidity, the connection between intake temperature and water amount (calculated & measured) is linear, but the measured water rises with temperature. This is due to the effect of temperature, which increases the volume of water vapor hiding in the air by raising the temperature to the same relative humidity. The gap between measured and calculated productivity is caused by heat exchanger engineering specifications that are insufficient to fully condense moisture.
Figure (4) The effect of the inlet temperature on the water production.

Figure (5) represents the calculated and measured amounts of water. The y-axis represents the water amount in $ml/(m^3 \text{ of air})$ and the x-axis represents the number of tests. Each test has different operating conditions.

The measured data and equation results show that the same location of maximum productivity efficiency exists. Productivity rises with relative humidity and temperature, reaching its peak ($16.9 \ ml/(m^3 \text{ of air})$) at $32.9^\circ \text{C}$ and $49 \%$ humidity, and it’s lowest value ($6.85 \ ml/(m^3 \text{ of air})$) at $29.5^\circ \text{C}$ and $55 \%$ humidity. The fluctuation in both curves indicates the change in operating conditions. During the experiment, the discrepancy between the calculated and measured water yield rate remains nearly constant.
Figure (5) Comparison between the measured and calculated water yield rates.

In figure (6) the y-axis represents the humidity Rh in % and x-axis represents the dew point $T_d$ in °C (the readings were taking at constant inlet temperature range 28 to 28.4°C). The figure shows that humidity has a major influence on the dew point, because as humidity rises, the dew point rises, and temperature variations have minimal effect on the dew point when humidity is not constant. In this example, we have two places with 61% humidity but temperatures of 28.2°C and 28.4°C, indicating that the dew point rises as the temperature rises.
Figure (6) Humidity's Influence on Dew Point

Figure (7) shows the relationship between water amount in ml/m$^3$ at the y-axis and the x-axis represents the volumetric inlet flow rate $Q_{in}$ in m$^3$/hr. The figure demonstrates that the increase of the inlet airflow and temperature increases the water amount in both the calculated and the measured water yield at constant humidity $Rh=45\%$. The measured water production shows that when the temperature increases from 28.1°C to 31°C, the fraction of water in the air rises about to 61 %. At the same time, the rising ratio of water productivity in AWG reaches about 66 %, and when temperature drops from 32.2°C to 31.7°C, the ratio of calculated water yield drops about to 18 %, while the ratio of measured volume of water from AWG drops about to 17 %.
Figure (7) The influence of the intake airflow on water production.

In Figure (8) the y-axis represents the power in Wt/ml and x-axis represents the productivity of AWG in milliliters. The bar chart depicting the energy required for water production in (Wt/ml). When production is low, energy consumption is comparatively high, and vice versa. The energy required to generate one milliliter of water has a minimum of 0.43 Watt and a maximum of 1.43 Watt.

Figure (8) Energy Consumption of water Production.
4. CONCLUSION

The characteristics on which the emphasis was placed were primarily those that characterize AWG performance. The input temperature, relative humidity, and air flowrate are the factors in question. The dew point temperature was another parameter investigated. The analysis shows the electricity consumption related to water production.

The AWG results show the variance in performance of the AWG under different climatic conditions. The water production rate changed from a maximum of 1230 ml/hr to a minimum of 955 ml/hr in relation to the maximum quantity of water in the air. The highest water production efficiency (measured to the calculated) is 93.430 % and the lowest is 46.91 %. According to the results, water output is directly proportional to the relative humidity of the surrounding air, air inlet temperature and air flow rate. Basically, humidity must be greater than 30%.
REFERENCES


