

Water Purification in Atmospheric Water Generator

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ABSTRACT

Atmospheric Water Generator (AWG) is a machine that could save the Earth from running out of fresh water in the future. It is considered a perfect method for water production in countries that has high percentage of humidity. This machine extracts water from humid air using a power source that is used for decreasing the air temperature until reaching its dew point. At which water is condensed and collected to be used in different applications. But the collected water is considered distillate water as it doesn't contain any minerals that are very important for human health. Consequently, the collected water has to be treated to be compatible with the standards of drinking water. In this paper, spectrophotometer is applied to obtain the concentration of several constituents exist in the collected water, then water passes through ultraviolet unit to be disinfected, and finally minerals are added with specific quantities. The verification is achieved via simulation for mineral treatment process using Aspen HYSYS simulation program. While the validation is performed by experimental work for other processes. The results affirmed that the generated water is potable and satisfy the market needs according to the Egyptian standards. These results are also consistent with World Health Organization standards (WHO).

Keywords: Air water generator, Himalayan salt, Mineral bed filter, Purification system, Thermo-electric coolers

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1 INTRODUCTION

Air Water Generator machine is capable of producing potable water from air, the main idea behind this technology is the condensation phenomenon [1, 2]. This

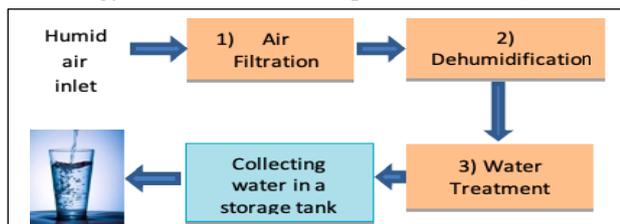


Figure 1: AWG process

machine is mainly composed of three basic operations as shown in Figure (1) that are:

1.1 Air filtration

In which dust, particulate matters, and any other undesired particulates are eliminated [3].

1.2 Dehumidification

Air dehumidification is performed by condensation of water vapor that exists with air. In this step, air is cooled to reach a temperature below its dew point, where at the dew point the air becomes saturated with water vapor, and any further cooling results in water condensation.

The dew point depends mainly on the temperature and relative humidity of air (the ratio between the actual amount of water vapor in air and the amount needed for saturation) as shown in Figure (2) [2]. There are several methods to achieve air condensation such as:

- Using a cooling coil, and a suitable refrigerant to cool the inlet air to a temperature at which water can be condensed and collected [4].
- Using Peltier effect of semiconducting materials, in which one side of the material is heated while the other side is cooled, this can be done using Thermo-Electric Cooler (TEC) [5].
- Cooling followed by sudden expansion in a condensation chamber [6].

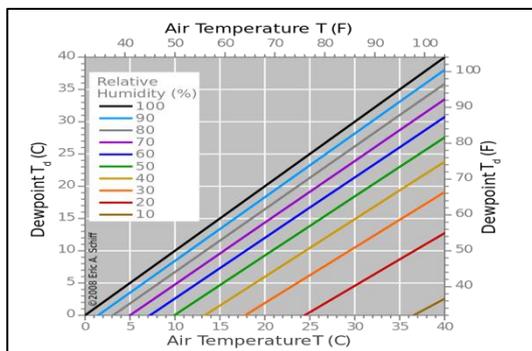


Figure 2: Dew point temperature versus the air temperature [7]

1.3 Water treatment

After generation of water, it is assumed that it will be safe, however it may contain dissolved minerals, organic compounds or even live organisms with harmful concentrations. Not only contaminated water can affect human health, but also water that contains unbalanced concentrations of some minerals can result in quality issues such as unpleasant taste [8]. In this manner; air water generators utilize two stages of filtration and salt addition stages. In the entrance of the air, pre-filtration is applied as mentioned previously, while in the post filter stage; water passes through several stages such as ultra violet (UV), ozone, multi-stage mineral and carbon filters. These stages are applied for addition of minerals and elimination of bacteria that could be present in the water.

To determine the amount of minerals required and to make sure that the outlet water from the air water generator can be consumed without any hazardous effect on human health, several tests must be performed. Water tests are mainly classified into Physical, mineral/inorganic, and microbiological tests [9].

1.1.1 Physical tests

These tests are performed to adjust the physical properties of the water sample such as its color, turbidity and odor.

1.1.2 Mineral tests

They are applied to obtain the concentration of minerals in the generated water, these tests are used to know if the minerals content is enough to consider the water safe for the human health. Generally; the concentration of various elements such as calcium, magnesium, manganese, iron, and others are obtained in the mineral tests, but in the case of the water generated from air, not all minerals are suspected to be present in the water, so only main elements will be tested [10, 11].

They may be conducted through different methods as follows [12]:

- Test strips: In these tests small strips are used to indicate the amount of several minerals, where the change in their colors indicates the amount of the existing minerals, but they are considered the least accurate method to obtain the results.
- Color disk kits: the sample to be tested is placed into a box containing kits which include some reagents to be used. Then the resulting color is compared with a color disk to indicate the concentration of each chemical.
- Hand-held digital instruments: They are portable devices such as digital meters, pH meters, ...etc. These devices are used to provide fast and accurate results.
- Lab equipment: There is several lab equipment needed for water quality testing, the main disadvantage is the high cost, however, they give the most accurate results and their presence is crucial to determine water quality such as spectrophotometers, biological oxygen demand chambers, ... etc.

1.1.3 Microbiological tests

They generally indicate the presence or absence of bacteria especially disease-causing bacteria. These types of tests are needed in the water collection section in the air water generator to make sure that the water is bacteria-free. As the possibility of aerobic bacteria growing increases in the collection tank where water usually is exposed to air, so a disinfection system must be applied. There are two ways for water disinfection; the chemical and non-chemical techniques [10, 11].

A. Chemical techniques for water disinfection

These techniques based on using several chemical reagents to keep the collected water free from bacteria. These chemicals have various types such as [13]:

- Ozone: it is an oxidizing agent, it is considered as bactericide and viricide, it also does not persist in water. ozone is not only used as a bacteria-killer but also it helps in deodorizing by breakdown many organic compounds that cause the unpleasant odor.

- Chlorine: it is widely used as a disinfectant due to its availability and low cost. It has a strong effect in the disinfection process as it keeps both the water in storage and the distribution system free of organisms and bacteria.

B. Non-chemical techniques for water dis-infection

The non-chemical ways are systems used to keep the water disinfected such as Ultraviolet radiation (UV). It is used in a specific manner in which the ultraviolet intensity and the contact time are adjusted to kill the bacteria and pathogens [13].

Water generated from the AWG is considered to be distilled water, which means it does not contain the minimum concentration of salts and may cause adverse health effects to humans, that is why the generated water must be analyzed, and the results must be compared to the Egyptian standards. Table 1 shows the Egyptian standards for drinking water (according to the Egyptian ministry of health decree number 458/2007 and the Egyptian guidelines standard 190/2007).

Table 1: The Egyptian standards for drinking water [14]

Constituents		Microbiological	
Parameter	Accepted limit (PPM)	Parameter	Accepted limit
pH	6.5-8.5	Total Plate Count at 22 °C/48h	<50 cfu/ml
Total Hardness (CaCO ₃)	<500	Total Plate Count at 37 °C/48h	<50 cfu/ml
Total Alkalinity (CaCO ₃)	<120	Total Coliform	No growth
Total dissolved solids (TDS)	<1000	Fecal Coliform	No growth
Calcium	<140	Fecal Streptococci	No growth
Magnesium	<36	Blue Green Algae	No growth
Potassium	<10	E.coli	No growth
Chloride	<250		
Sulfate	<250		
Ammonium	<0.5		
Nitrates	<45		
Total Iron	-		
Total Chlorine	-		
Free Chlorine	-		

This paper has two objectives, the first one is to discuss the main parts of the air water generator in addition to its working conditions, and the second part is to discuss the purification system needed for the device and obtain the optimum quantities of minerals that should be added to get safe water to be used in drinking purposes.

2 EXPERIMENTAL WORK

2.1 Equipment used for testing

To perform the laboratory experiments several equipment were used, the following section summarizes

the equipment used and the information regarding each one.

2.1.1 Spectrophotometer

It is applied to know the concentration of each constituent in water to guarantee that the water is safe and suitable for human use. These tests are performed through Hach spectrophotometer (model number DR3900) that exists in the Egyptian Academy for Engineering and Advanced Technology using the kits shown in Table 2.

Table 2: Kits needed for water tests

Element to be tested	Kits for Hach spectrophotometer
Free chlorine	Free Chlorine Powder Pillow
Total chlorine	Total Chlorine Powder Pillow
Sulfate	Sulfaver 4
Iron	FerroVer
Copper	CuVer
COD	Vials
Alkalinity	Alkalinity test kit
Hardness	Hardness test kit

2.1.2 Digital Titrator

It is used for titration purposes to perform quantitative analysis by which the quantity of each constituent is obtained. In this paper Hach digital titrator is used that exists in the Egyptian Academy for Engineering and Advanced Technology.

2.1.3 Digital reactor

It is applied to raise the temperature of vials to a certain temperature in a certain time in order to be used in the determination of the chemical oxygen demand (COD) of water samples. This process is done in Hach digital reactor with model DRB200 that is provided from the Egyptian Academy for Engineering and Advanced Technology.

3 SYSTEM CONFIGURATION AND RESULTS

The obtained water from AWG electro-mechanical part has to be treated as shown in Figure 3. The water treatment part consists of disinfection, and mineral addition. The condensed water from AWG moves by gravity to a first collection tank. Then the UV unit is used to ensure that the water is bacteria free. The outlet water from this unit either returns to the second collection tank or passes to a mineral filter. This mineral filter is a final stage to add the needed minerals for the final use.

3.1 Water condensation stage

Thermo-electric coolers (TECs) were used to reduce the temperature of air to reach the dew point of the water vapor to be able to condense water from it. In this model, air is forced to move inside the tube using a blower located below the suction line, a filter is used to hold back dust and suspended matters from entering the loop, the air temperature is reduced using six TECs to reach the dew point, the system is isolated from the ambient temperature, then the condensed water flow to the collection tank by gravity. This model was applicable to deliver one liter of water per day, taking into consideration that the humidity of air should exceed 40 % and for maximum performance the humidity should exceed 50-60%. This model can be operated using a portable solar cell that provides the power needed.

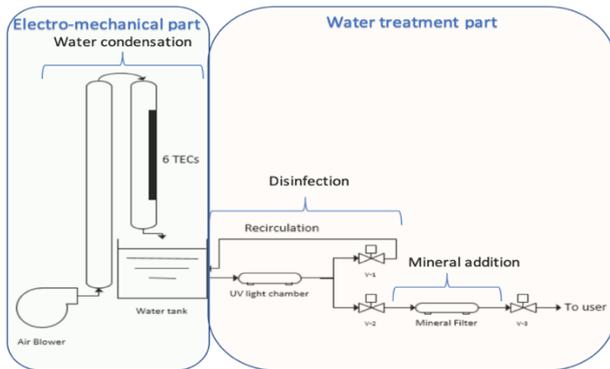


Figure 3: Water Purification System

3.1 Water disinfection stage

The generated water must be bacteria-free, that is why a disinfection system must be integrated into the design. The system consists of a UV source surrounded by a hollow cylinder as shown in Figure 4, in which water passes to be totally subjected to the UV beams to perform the disinfection process by eliminating the undesired bacteria. In this equipment there are two scenarios, if the user demands the water, the water will pass through the UV system to ensure that the water is bacteria free, then through the mineral filter and eventually reaches the user.



Figure 4: UV light disinfection system

On the other hand, if the water remained in the tank for three days recirculation of water using UV light will take place to make sure that water is bacteria free in the

tank. Table 3 summarizes the specifications regarding the UV disinfection system. Then microbiological examination was performed on the generated water after passing through the UV system, and the results are tabulated in Table 4.

Table 3: Specifications of the UV system

Specifications	
Type	UV water sterilizer
Model	SS 4W-12W
Power (W)	6
Flow rate (L/min)	1.9

According to the test results, the water is safe for drinking and household uses, where it is compliant with WHO standards and, and the Egyptian Ministry of Health decree No. 458/2007 and the Egyptian guidelines standard 190/2007.

Table 4: BOD test results

Test to be analyzed	Result	Units
Total Plate Count at 22 °C/48h	Zero	Cfu/1ml
Total Plate Count at 37 °C/48h	9	Cfu/1ml
Total Coliform	-ve	Cfu/100ml
Fecal Coliform	-ve	Cfu/100ml
E. coli	-ve	Cfu/100ml
Fecal Streptococci	-ve	Cfu/100ml
Blue Green Algae	-ve	Cells/1ml

3.1.1 Minerals addition stage

There are several methods for salt addition, such as using calcite powders, dolomite stones, Himalayan salt and so on. In the first configuration, ratio controllers are used to control the dosage pumps to make sure that the right amounts of salts are pumped as shown in Figure 5.

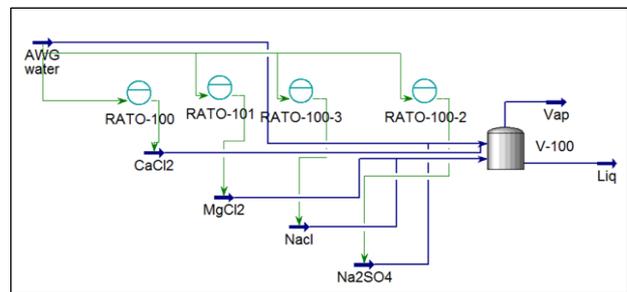


Figure 5: HYSYS Simulation for different chemicals addition

This approach is impractical as it requires using four pumps and four ratio controllers. It will be costly for real time applications. Another alternative way to add salts is to use Himalayan salt. Himalayan salt contains 84 trace minerals [15-18], and it has the advantage of low cost as one kilogram of the salt costs around 100L.E. Table 5 shows the constituents of the salt.

Table 5: Himalayan salt constituents [15-18]

Content	Percent (%)
NaCl	97.46
Magnesium as MgCl ₂	0.25
Sulfate as Na ₂ SO ₄	0.88
Calcium Sulfate as CaCl ₂	0.38
Iron	3
Moisture	0.03
Water insoluble	1

By using this salt, the simulation will be altered to use only one dosing pump and one ratio controller as shown in Figure 6.

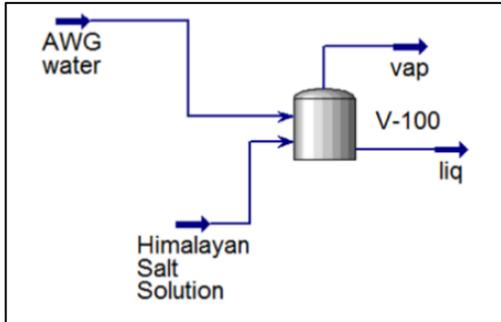


Figure 6: HYSYS simulation for Himalayan salt addition

Using aspen HYSYS, the amount anticipated for salt addition of water flowing at a rate of two liters per hour is 0.1 milli-liter of Himalayan salt solution. To calculate the amount needed of Himalayan salt experimentally, different dosages of salt are used, then the collected water (after salt addition) is analyzed using spectrophotometer. It was found that 0.125 gm of salt are used for the treatment of 1 liter of water to get the results tabulated in Table 6.

As shown in Table 6, it is clear that the concentration of constituents in the generated water did not exceed the limit levels according to the water quality standards in the right column. However, two ways to add salt: the former one is the manual addition by user and the later one using pump. The manual addition is impractical. While, using pump is a not a cost-effective solution and not accurate to get the standard potable water with variable water quantity in the tank.

Table 6: Water constituents after lab experiments

Constituents	Distilled water after salt addition (PPM)	Water generated after salt addition (PPM)
Copper	0	0
Free Chlorine	0	0.03
Total Chlorine	0	0.01
Alkalinity CaCO ₃	385	385
Sulphate	1	2
Iron	0.01	<0.02
TDS	165	130
Hardness CaCO ₃	60	80
Na	40	40
COD	Below 150	Below 150

Another practical solution is applied using mineral bed filters which contains layers of salts and mineral stones to adjust the water constituents. To adjust the resulting constituents both flow rate and mineral stones height in the vessel are altered until reaching the desired output. The dimensions of the filter are calculated according to the water flowrate. Figure 7 shows the mineral bed filter and illustrates the configuration used in this section.



Figure 7: (A) Water Addition filter and UV system (B) Configuration of mineral addition test

Table 7 shows the results of each parameter after mineral addition using bed filter and it is found that the constituents are below the limits, so the water is considered to be safe for drinking and household use.

Table 7: equipment configuration and mineral bed filter constituents

System Specification			
Water flow rate (liter per hour)		100	
Filter shape		Cylindrical	
Filter height (cm)		48	
Filter diameter (cm)		2	
Generated water constituents			
Parameter	Value (PPM)	Parameter	Value (PPM)
pH	8	Sulfate	3
Total Hardness (CaCO₃)	14	Total dissolved solids (TDS)	64
Calcium	2	Ammonium	<0.01
Magnesium	1.2	Nitrates	0.32
Total Alkalinity (CaCO₃)	12	Total Iron	0.01
Sodium	5	Total Chlorine	<0.02
Potassium	0.5	Free Chlorine	<0.02
Chloride	5.9		

4 CONCLUSIONS

The condensed water from the AWG is at distilled water with a pH of 7 and total dissolved solids of 50 ppm. A water treatment process is applied to obtain potable and safe water. The applied treatment consists of:

- UV unit with a capacity of 1.9 liter per minute water sterilizer was used
- Mineral bed filter is used as a best solution to add needed salts

Different operations to add minerals were investigated and the best one is chosen as bed filter. The bed filter dimensions are calculated for average water flow of 100 liter/Hr. The bed height was found to be 48 cm and the diameter is 2 cm using trial and error. Mineral filters are better in energy consumption, and can withstand the fluctuations in the generated water quantity. The analysis for the drained water to user affirmed the potential of the applied experimental work. The obtained results are consistent with Egyptian standards and also with WHO standard

Conflicts of interest

There are no conflicts to declare.

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