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Potable Water Generation from Atmospheric Moisture in Coastal Areas Using the Thermoelectric Effect

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Abstract

Purpose: *Although water covers more than two-thirds of the Earth's surface at nearly 70%, potable water is still scarce and insufficient to the consumption rates stipulated by the standards of the World Health Organization (WHO). Therefore, many countries, where fresh water resources are scarce, have directed their efforts to conducting research and studies to find suitable ways to provide drinking water from non-conventional sources. Researchers have found multiple ways to desalinate seawater; such as reverse osmosis devices, evaporation and re-condensation of sea water, recycling polluted water, or drilling artesian wells to extract groundwater. However, the disadvantage of these methods is that they are financially costly and require the region to be located in a geographical area close to the sea. They may also be disrupted for various technical reasons; such as lack of energy to operate or damage to mechanical parts.*

Design/Methodology/Approach: *This study was conducted using quantitative methodology by collecting information about weather conditions in the geographical area of the northern coast of the city of Alexandria at geographic coordinates (Lat. 31.2 and Long. 29.95). It aims to design a device for generating water from atmospheric air using the thermoelectric effect (Peltier effect), which is characterised by simplicity of design and distance from complex mechanical installations. It is used to solve the problem of drinking water scarcity on the northern coast of Egypt, which is characterised by the relatively high humidity of air (60-70%), especially during the months from January to August.*

Findings: *The results have reached the possibility of using this device to generate 2.86 litres/hour of fresh drinking water at a temperature of 30 degrees Celsius and a relative humidity of 60% with an average electrical energy consumption of 0.02 kW/h/litre. This amount is suitable for the daily consumption of a family consisting of (4-5) adults according to the standards of the World Health Organization (WHO), as it is economically inexpensive in terms of its electrical energy consumption.*

Key-words:
Atmospheric Humidity, Dehumidification, Moisture Harvesting Relative humidity, Water Capture, Water Generation, Peltier effect, Thermoelectric.

1. INTRODUCTION

According to the World Health Organization (WHO), clean water is essential to human health. However,, almost 800 million people in the world do not have access to clean water. The reasons for this are many and varied, yet they include factors such as climate change, poverty, and poor infrastructure. In addition, the demand for water is increasing all the time as the world's population grows. Researchers have resorted to finding various alternative sources to traditional sources of drinking water to overcome the problem of providing potable water from their traditional sources. These include using recycled waste water, using desalination plants, and tapping into underground water supplies. These methods have various drawbacks, such as the need for infrastructure, expensive technology, and the potential for environmental damage.

In the context of the search for a source of potable water characterized by the possibility of providing it anywhere in the world and at the same time having good economic feasibility, this research paper deals with an attempt to generate potable water from the moisture content in the air. By using a process known as humidification, it is possible to extract water from the air. This process is not only technically feasible, but it also has the potential to be cost-effective. When tackling the problem of water generation from the atmosphere, the first step is to analyze various dehumidification methods. This research looks into how to extract potable water from the atmosphere using advanced technology that is as free of problems as possible when compared to other technologies.

During the preliminary investigation, three common psychometric dehumidification strategies stood out for lowering the temperature below the dew point (condensation by refrigeration), pressure consolidating, or a combination of the two. In addition to this technique, the wet desiccation technique can be used for the aforementioned purpose. These strategies are discussed in more depth until the technical problems with these techniques become clear. The most traditional method for converting the moisture content of the air into water is dehumidification. Refrigeration by using of traditional refrigeration cycle relies on passing air over cooling coils to lower the dew point of the air, and this is shown in Figure 1 (Michael Giglio 2015)

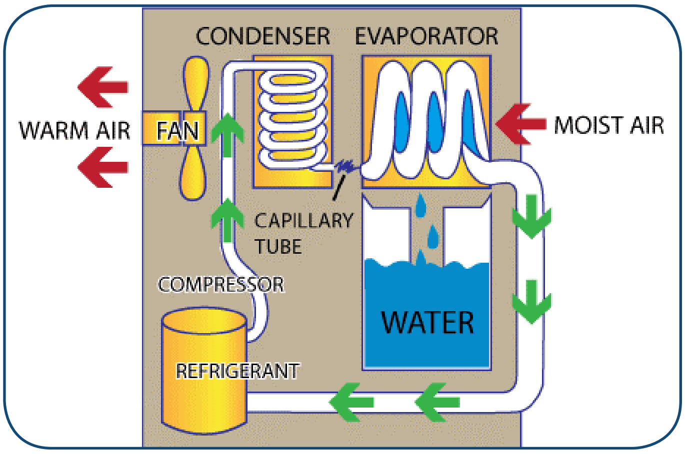

Fig. 1. Dehumidification by refrigeration (Michael Giglio 2015)

For more clarity, the traditional refrigeration circuit is also called the vapour compression cycle, which is shown in Figures 2 and 3. The compressor, condenser, expansion valve, and evaporator are the four main parts of the basic vapour compression cycle, respectively. This four equipment are connected to tubes in which the refrigerant is circulated. When the compressor starts receiving the refrigerant as a saturated vapour, its pressure and temperature are raised at constant entropy until it reaches the highest pressure and temperature values in the cycle before entering the condenser.

Through the condenser, the temperature of the refrigerant is reduced when the pressure is constant and converted to the liquid state before it enters the expansion valve by rejecting the amount of heat that the refrigerant has gained outside the cycle. The refrigerant enters the expansion valve to reduce its pressure to the lowest value, which is the value equal to its pressure before entering the compressor, and that is when the enthalpy is constant. After the refrigerant exits the expansion valve, it enters the evaporator, which converts it back to saturated vapour by absorbing the latent heat from the surrounding medium (Animesh Pal 2018).

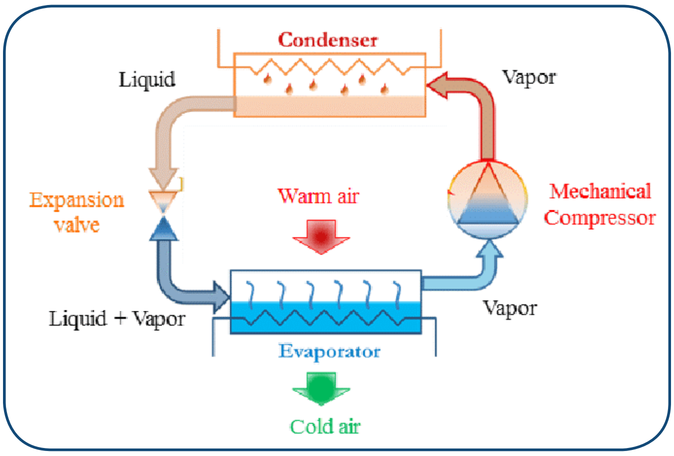

Fig. 2. Vapor compression cycle equipment (Animesh Pal 2018)

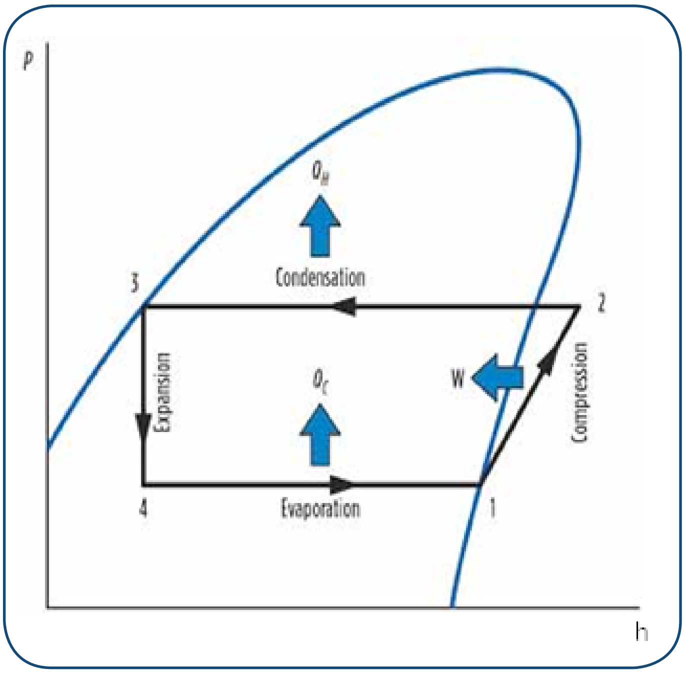

Fig. 3. Vapor compression cycle (p-h) diagram (H. Y. Noh, 2019)

One of the techniques also used to convert atmospheric moisture into water is air compression dehumidification. This technology depends on raising the pressure of the wet air until the dew point rises and the air condenses at the temperature of the surrounding medium. The air pressure can be five times the atmospheric pressure until it reaches the degree of condensation. The degree of condensation ranges from 2 to 3 OC which requires air tanks with strong walls that can withstand pressures up to 5 bar,as shown in Figure 4 (Ionmax, 2022).

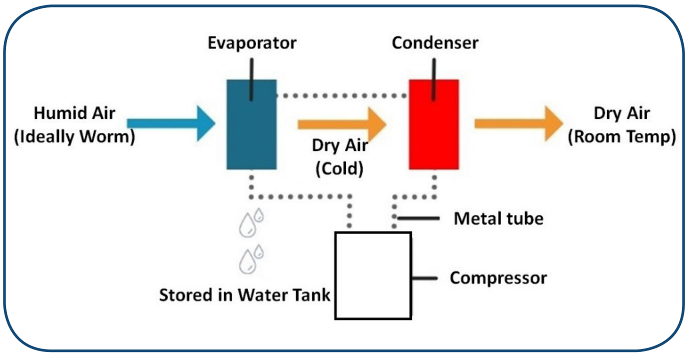

Fig. 4. Air Compression dehumidification (Ionmax, 2022)

Not only that, but there is another way to get water from atmospheric humidity which is called dehumidification by liquid desiccant. It is the technology of removing humidity from the air using liquid desiccants and it depends on the absorption of water vapor from the air by passing it through a special chemical solution such as Bentonite Clay, Silica Gel, Molecular Sieve, and Carbon (CLARIANT, 2022)The ability of the chemical solution to absorb humidity from the air depends on its concentration and temperature. Figure 5 shows the installation of the device used to remove humidity from the air (TROTEC, 2022).

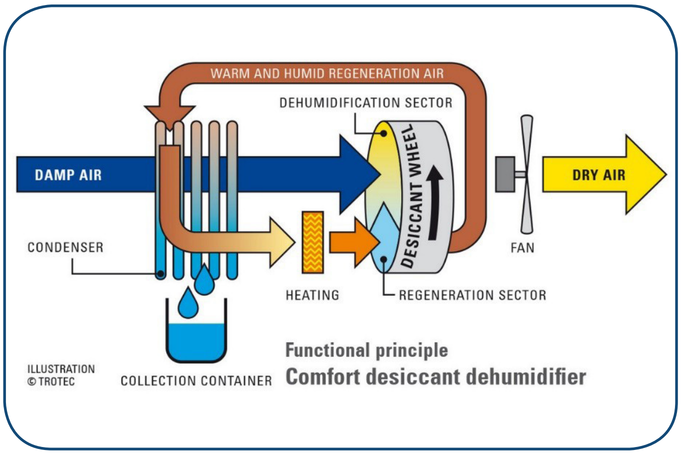

Fig. 5. Dehumidification by desiccation (TROTEC, 2022)

Due to the disadvantages of the previous methods in terms of the presence of complex mechanical parts or the use of materials that may negatively affect human health, such as freons and moisture-absorbing chemicals, the idea of using another method to generate water from the moisture content in the atmospheric air, which is the method called (Thermoelectric Refrigeration) arose. This technology is equivalent to vapor compression technology, but it depends on converting the difference in voltage between the ends of the thermocouple into a difference in temperature and vice versa. One of the most famous applications that depend on the thermoelectric effect is the so-called (Peltier) technology, as shown in Figure 6 which illustrates the Peltier effect device (Pravinchandra, 2015).The main reasons for this technology's being superior to that of other technologies used to extract potable water from the atmospheric air humidity are (compact size, few mechanical and rotating parts, need for regular simple maintenance in order not to make much noise) (Solutions, 2022, Nandy et al., 2014, Nitheesh et al., 2019, Suresh P S*1)

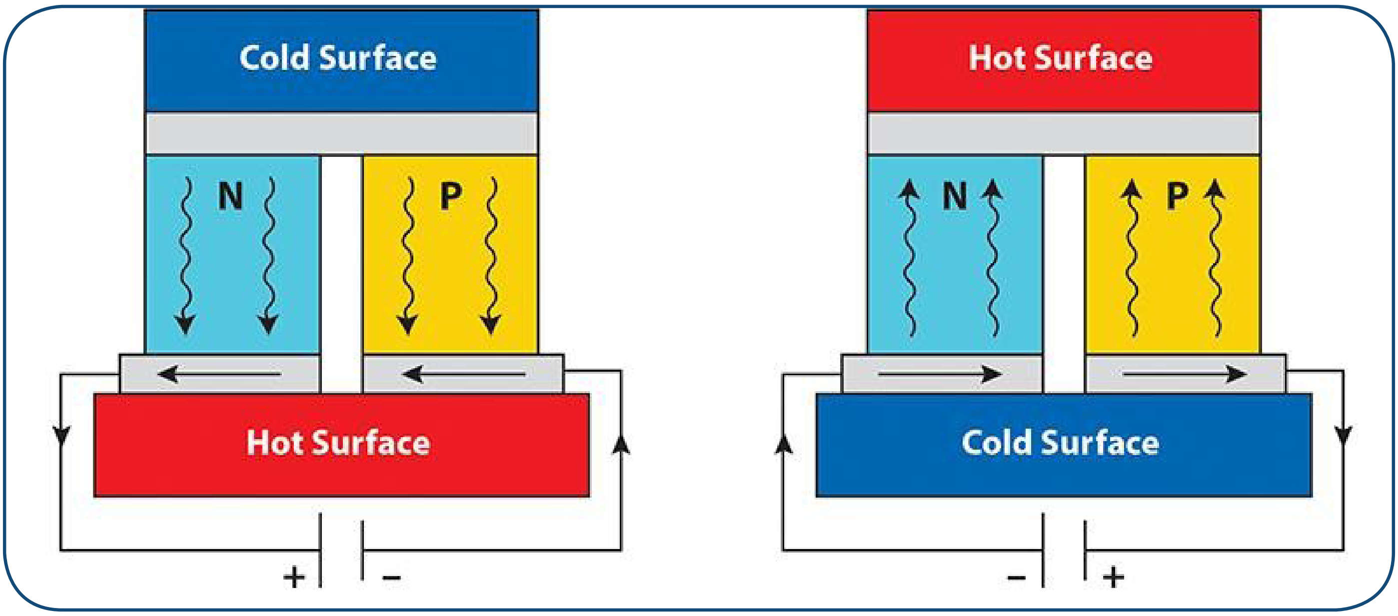

Fig. 6. Peltier refrigeration device
(Icecube, 2022)

In order to obtain accurate scientific results that can be measured and generalized in the future from the use of the thermoelectric effect method in generating water from the moisture content in the atmospheric air, the geographical area located on the northern coast of Egypt, specifically on the northern coast of Alexandria, was chosen at the geographical coordinates (latitude: 31.2 and longitude: 29.95) as a case study.

LITERATURE REVIEW

By reading the scientific researches that are interested in studying and evaluating the vapour compression refrigeration system, including (Anbarasu, 2011), it becomes clear that despite the effectiveness and spread of this system, it is flawed as follows:

- It needs a traditional energy source to supply it with the energy needed for operation;
- It is difficult to provide portable units of the type of vapour compression systems;
- It requires the presence of mechanical equipment in its installation such as the compressor and expansion valve; and
- It can produce noise during its operation.

By reading the scientific researches that focus on studying and evaluating the system of dehumidification using the desiccant, including (Khan et al., 2022), it is possible to notice the small amount of potable water that can be extracted using this technique, which may not exceed the right of one ml / kW.h, in addition to the high cost of material needed For manufacturing. Through the study of scientific research that dealt with the extraction of potable water from atmospheric air using Pelier effect technology (Kabeel et al., 2016), among which it is clear that this technique is the most technology that is free from the problems of previous technologies due to its distinctiveness as follows:

- Small (compact) size.
- It needs maintenance more easily than other methods of obtaining fresh water such as reverse osmosis devices or vapour compression systems.
- Environment friendly.
- It is possible to produce portable units from it.
- It can be operated using renewable energy methods such as photovoltaic and solar energy as the rate of energy consumption required to generate one litre of fresh water is approximately 0.02 kilowatt hours.
- It can be used easily in remote places.
- Produces reasonable quantities of potable water where it can produce about 3 litres of fresh water per hour, which is enough to consume a family consisting of 4-5 adults according to the standards of WHO.

This article aims to solve the problem of potable water scarcity in the northern coast of Egypt, which is characterized by the high relative humidity of air in the atmosphere (60-70%) by designing a portable water generator that meets the following conditions:

- Applying WHO standards for safe potable water ((W.H.O). 2017).
- Small size and the ability to move easily.
- Simplicity in design and avoiding complicated mechanical installations.
- Not relying on traditional energy sources for operation as the generation of one litre of potable water does not need more than 0.02 kW.h.
- The possibility of operation by non-specialists.
- Safe operation.
- Low Cost.

This depends on the (Peltier Effect) and takes the energy necessary to operate it from solar energy. This water generator can generate 3 litre/h of fresh potable water which satisfies the needs of a family of 4-5 adults according to the standards of WHO.

METHODOLOGY

In this research paper, a quantitative research methodology is applied by collecting atmospheric conditions (temperature and relative humidity) at different times throughout the year for the geographical area that has been identified to conduct the study, which is the northern coast of Alexandria. This information will be considered as the starting point conditions for the cooling process necessary to condense the air humidity and turn it into water. After that, the type of fan that will pump the air into the cooling system is chosen, where the conditions for air exit from the fan is considered as the end-point conditions for the cooling process.

After defining the conditions for the start and end points of the cooling process based on the previously collected data, this data are entered into a computer program for psychometric calculations to determine the water rates that can be obtained from condensing moisture content in the atmosphere. After obtaining the results from the psychometric process of condensation, the use of these results are for selecting the appropriate components of a thermoelectric cooling system (Peltier) that will be used in the design of the device needed for water generation.

Wither Data Collection

According to Egypt Climate Charts Index (Climate, 2022), it can be observed that the temperature ranges between 2-40 OC and relative humidity ranges between 60-70% in Alexandria throughout the entire month of the year, as shown in Table. 1 and Figure 7.

Table. 1: Temperature Distribution Throughout the Year
(Climate, 2022)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum Temperature in (°C)	27.7	32.7	38.4	43.4	45.1	44.6	39.0	40.0	39.8	37.9	35.2	29
Minimum Temperature in (°C)	2.2	2.8	3.3	6.8	10.1	13.4	17	18.6	15	11.2	10.3	4.4
Average Temperature in (°C)	14.95	17.75	20.85	25.1	27.6	29	28	29.3	27.4	24.55	22.75	16.7

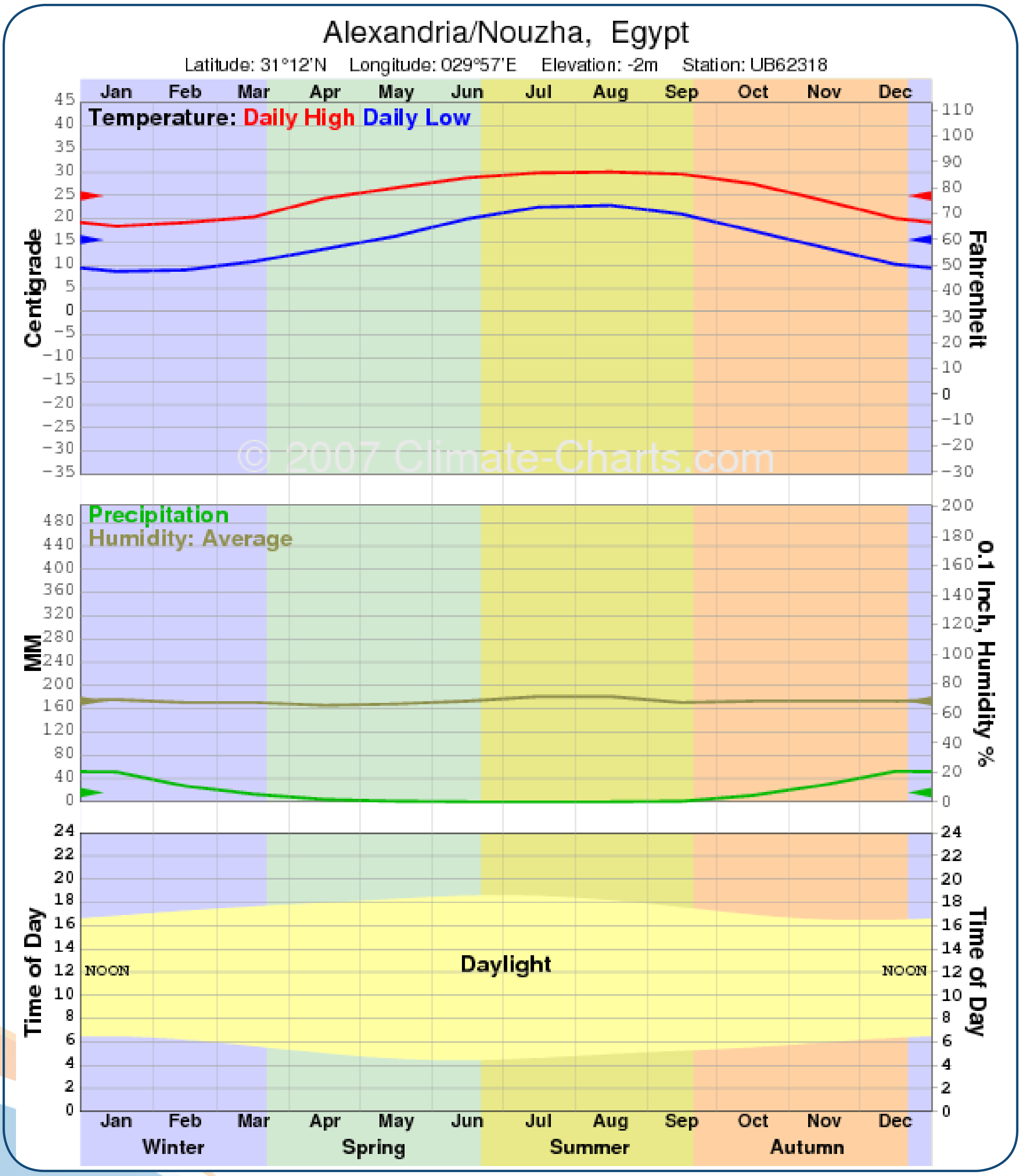

Fig. 7. Alexandria climate average weather data (Climate, 2022)

Air Supply Fan Selection

Select (Dayton 6KD70 Fan, Axial, 108 CFM, 12 V) (Dayton, 2022) which shown in Figure 8 and has the following specifications as shown in Table. 2

Fig. 8. Dayton 6KD70 fan (Dayton, 2022)

Table. 2: Dayton 6KD70 Fan Specifications (Dayton, 2022)

Body Material	PBT
Brand Name	Dayton
Color	Black
Item Weight	0.010 ounces
Model Number	8541603174
Noise Level	42.0 decibels
Number of Items	1
Part Number	6KD70
Specific Uses For Product	Personal
UNSPSC Code	43201619

Using Psychometric Chart Software

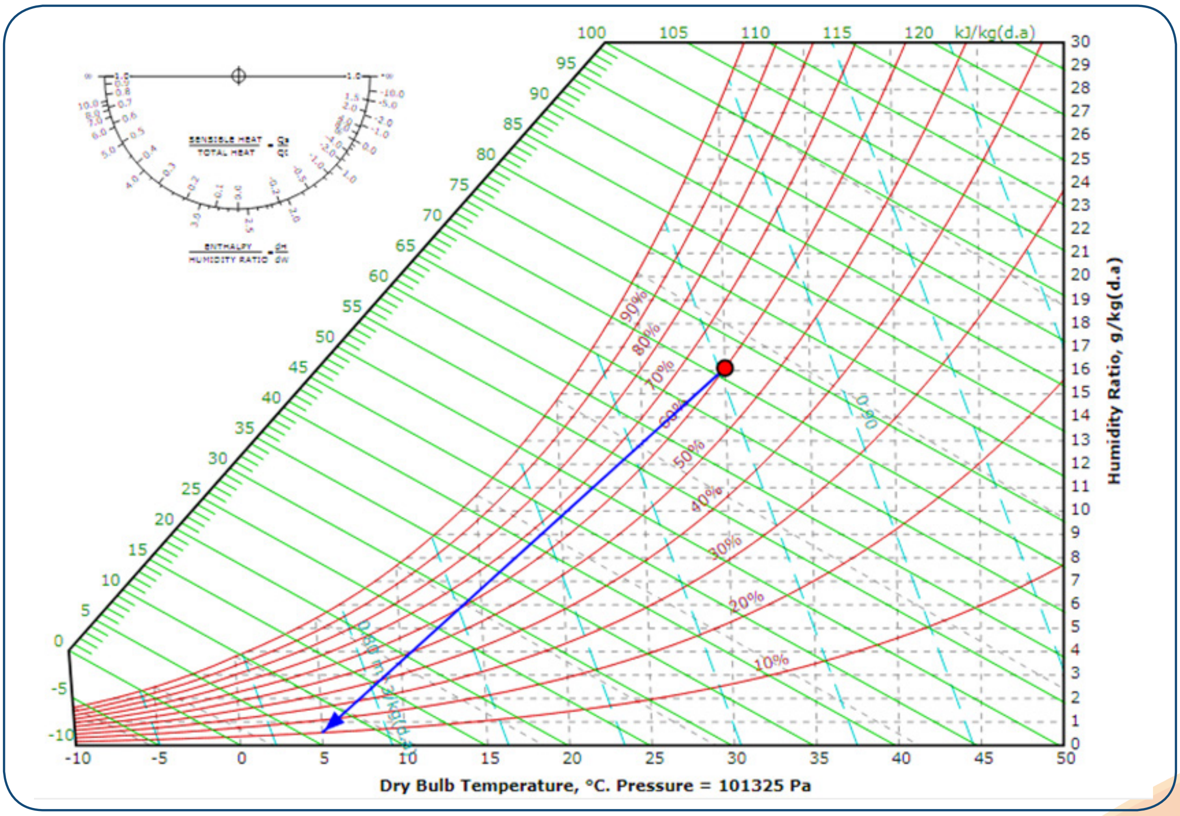

Fig. 9. Dehumidification process in psychometric chart (FlyCarpet, 2022)

By using Psychometric Chart software V4.4 as shown in Figure 9, the inlet and outlet humid air condensation process properties will be as shown in Tables. 3 and 4.

Table. 3: Humid Air Inlet Properties

Property	**Value**	**Units**
Rate of Air Mass Flow (m)	0.05	kg / s
Pressure	101.325	kPa
Dry Bulb Temperature (T_{db})	30	^{o}C
Wet Bulb Temperature (T_{wb})	23.8	^{o}C
Enthalpy (h)	71.4	kJ / kg
Absolute Humidity (H)	16.12	g / kg
Relative Humidity (R.H)	60	%
Dew Point Temperature (T_{dp})	21.4	^{o}C

Table. 4: Humid Air Outlet Propertie

Property	**Value**	**Units**
Rate of Air Mass Flow (m)	0.05	kg /s
Pressure	101.325	kPa
Dry Bulb Temperature (T_{db})	5	^{o}C
Wet Bulb Temperature (T_{wb})	-2.4	^{o}C
Enthalpy (h)	6.4	kJ / kg
Absolute Humidity (H)	0.538	g / kg
Relative Humidity (R.H)	10	%
Dew Point Temperature (T_{dp})	-24.1	^{o}C

According to the results obtained by the program and recorded in both Tables 4 and 5 ,the following results can be reached:

- The Rate of Generated water amount = 2.86 L/h.
- The energy required to produce ptable water per litre = (inlet enthalpy – outlet enthalpy) / amount of generated water. = (71.4- 6.4)/ 2.86 = 0.02 kW.h/litre.

Peltier Module Selection

By using Peltier – Thermoelectric Cooler Module Calculator (TE Technology, 2022) software according to the previously obtained results, the selected peltier module will be (CH-41-1.0-0.8) and its specifications are as shown in Figure 10 and Table 5.

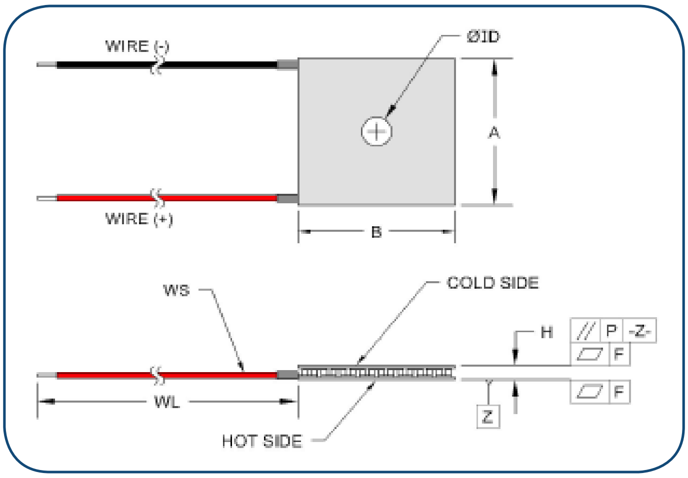

Fig. 10. Peltier module (CH-41-1.0-0.8) (Technology, 2022)

Table. 5: (CH-41-1.0-0.8) Peltier Module Specifications

Specifications	(27 °C)	(50 °C)
(Volt) V_{max} (V)	5.3	5.9
(Current)I_{max} (A)	5.7	5.7
(Power) Q_{max} (W)	18.6	20.4
Max T_{db} (°C)	68	77
Storage/ Operation Temperature	(- 40 °C) to (+80 °C)	

(Technology, 2022)

Potable Water Capture Device Layout

After completing the calculations of the potable water generation rate, the selected device design is Shown in Figure 11 (Nurhilalb, 2016).

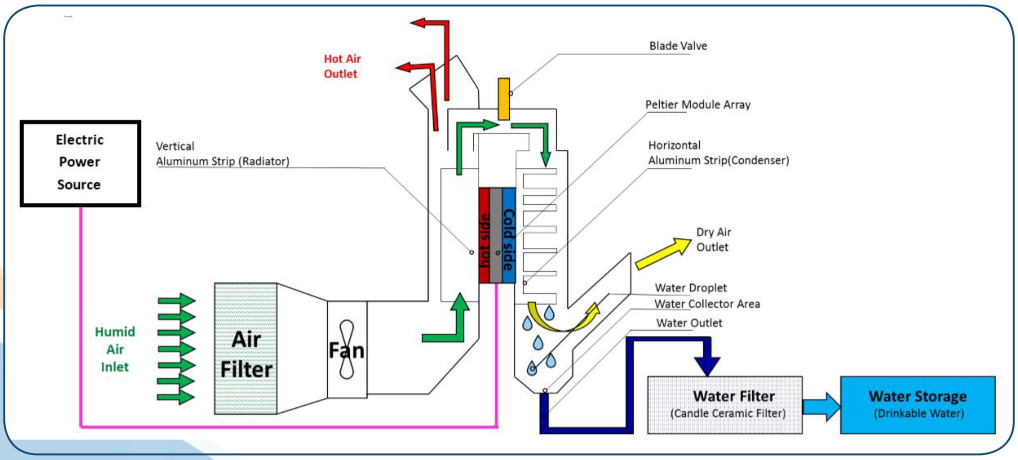

Fig. 11. Potable water capture device layout (Nurhilalb, 2016)

Drawing the curve of the relationship between relative humidity and the rate of water generation while holding the other variables, such as temperature and air flow rate, is constant, as shown in Figure 11. This reveals that there is a linear relationship between the two, indicating that as relative humidity rises, the rate of water generation rises as well.

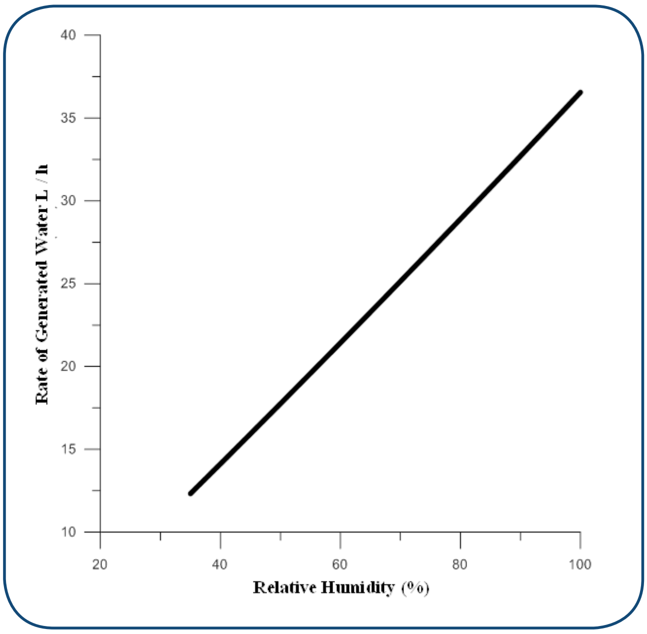

Fig. 12. Relationship between relative humidity and water generation rate

RESULTS AND DISCUSSION

At the end of this article and its findings, discussion can be as follows:

a) The device that was designed allows for the generation of up to 2.86 L/h of potable water from the atmosphere of the northern Egyptian coast at a temperature of 30 OC and relative humidity of 60 %, which is enough to supply a household of five adults with enough to drink. This is in accordance with the standards of WHO, which set the rates of consumption of water by an adult with a quantity of 3 to 4 litres per day. In comparison, the goal of designing the device for the purpose of providing the quantity of safe water per day has been achieved by 100%.

b) The goals for which the device was designed were achieved in terms of small size, simplicity of design, safety in operation and the ability to transport easily by one hundred percent.

c) As for the goals that are concerned with avoiding the use of complex mechanical installations such as rotating and reciprocating parts, they have been achieved at a large percentage that may reach ninety percent, due to the inability to dispense with the fan that continuously supplies the device with air, as this fan represents one of the rotating parts.

d) As regards the objectives that are concerned with dispensing with traditional energy sources, they have been achieved with a large percentage that may reach ninety percent until the implementation of another research concerned with the possibility of operating the device by relying on renewable energy sources.

e) Finally, for the goal that is concerned with studying the financial cost of manufacturing this device as a quantitative production, an independent research need to be conducted to compare it with other traditional methods used to obtain potable water.

CONCLUSION

The results obtained through the article can be summarized as follows:

1. The best way to provide potable water in places where traditional water and energy sources are scarce is to generate water from the moisture content of the atmosphere.
2. The most suitable refrigeration system that can be used to design a portable potable water from atmospheric air is the thermoelectric refrigeration system using pettier module.
3. A quantity of potable water can be generated from the atmosphere of the northern Egyptian coast at a rate of up to 2.86 L / h at a temperature Tdb = 30 OC, and relative humidity R.H = 60%.

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