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Renewable source powered thermo electric peltier device for the generation of potable water from the atmosphere suitable for the climatic conditions of Jabalpur

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Abstract
Billions of people do not have access to clean drinking water even though about 70% of the earth is covered with water. Clean drinking water is essential to the existence of life and has become the most precious and the most essential as there is no substitute for the water. Clean drinking water is very essentional for the functioning of body and life itself as bodies are having approximately 70% of water. Understanding the importance of safe, accessible and affordable drinking water, a beginning was made to create solutions that may be capable of recovering water from the atmosphere through various technical means in this context a comprehensive study has been made on various renewable resources based atmospheric water generator under the climatic condition of Jabalpur". The water generation capacity through Atmospheric Water Generator is entirely depends upon the Inlet Air flow, Humidity and Temperature and thus the amount of generated water increased with an increase in temperature, humidity and inlet air flow. The average Relative humidity of Jabalpur around 59.4% it vary from around 31% during summer (May) to 90% during the Mansoon (August).The most humid month of the year is August with humidity varies from 68.9% to 99.0%.The least humid month is of the year is May, with humidity varies from 13.9% to 54.5%. The Average Wind Speed is 2.8 m/s, Average temperature is 25.3 °C, (5.7 °C – 43.9 °C), The Average Dew Point is 15 °C (1 °C – 27.1 °C), Pressure 954.4 hPa (940.8 – 967.8).

Keywords: Atmospheric water generator (AWG), renewable energy, solar energy, thermo electrical cooler, perltier effect, relative humidity, DBT, WBT, Dew point

Introduction
The needs of human beings are mainly nutrition, clothing and shelter but above all there is a great need of water without which survival seems impossible. the availability of water is very limited compared to other sources. Keeping this problem in mind, the device has been formulated, conceived and designed to extract potable drinking water from the surrounding air available in the atmosphere, known as atmospheric water generator.

Water scarcity represents an emerging, severe global concern. According to research conducted by the World Health Organization, one-third of the world's population lacks access to clean water and the situation is expected to be exacerbated due to climate change by the year 2050. New technological interventions are urgently required to minimize groundwater stress and complement the suite of existing water generation technologies. In this context, atmospheric water generation (AWG), which extracts water from the humidity present in the atmosphere, could be viewed as a futuristic approach to address the issue of water scarcity. The water present in the atmosphere can be considered as a nearly inexhaustible resource for fresh water because at any given time approximately 13,000 km^3 of fresh water is in the atmosphere, which is naturally replenished through the hydrological cycle. The amount of water present in the local atmosphere at any given time depends on the temperature, pressure, and relative humidity (RH) of a location. then the amount of water present in air at different temperatures and RHs can be roughly estimated, as shown in Figure given below:

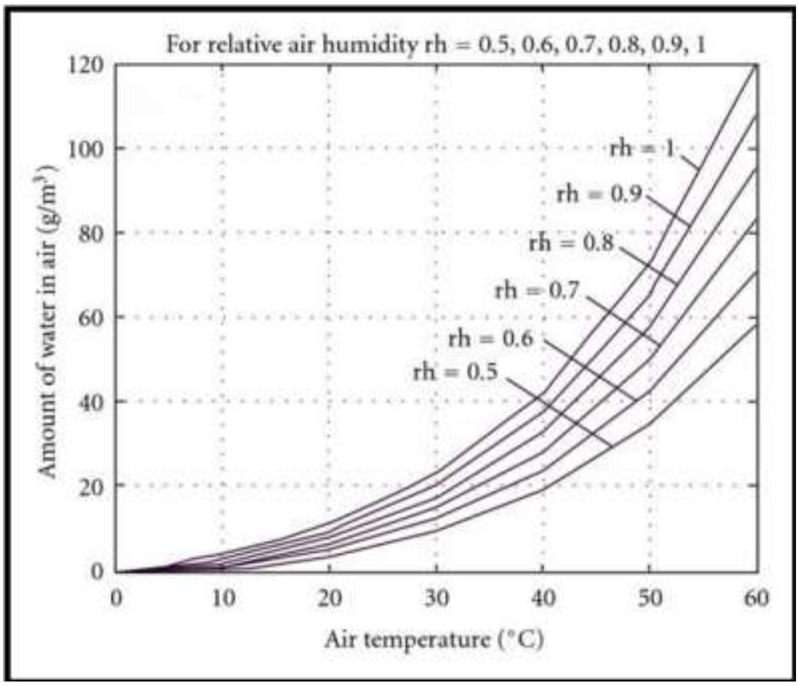

Fig 1: Amount-of-water-in-1m3-of-air-versus-air-temperature-and-relative-humidity-rh

Atmospheric water generation (AWG) uses various technologies to produce potable water from surrounding air. This provides the potential to expand water availability during shortages, contamination events, and other issues that can interrupt drinking water services. An atmospheric water generator (AWG), is a device that extracts water from humid ambient air, producing potable water. The strategy herewith being tackled the challenge of providing fresh drinking water to needy is harvesting of water from the ambient air through Solar Powered TEC Technology under the climatic condition of Jabalpur.

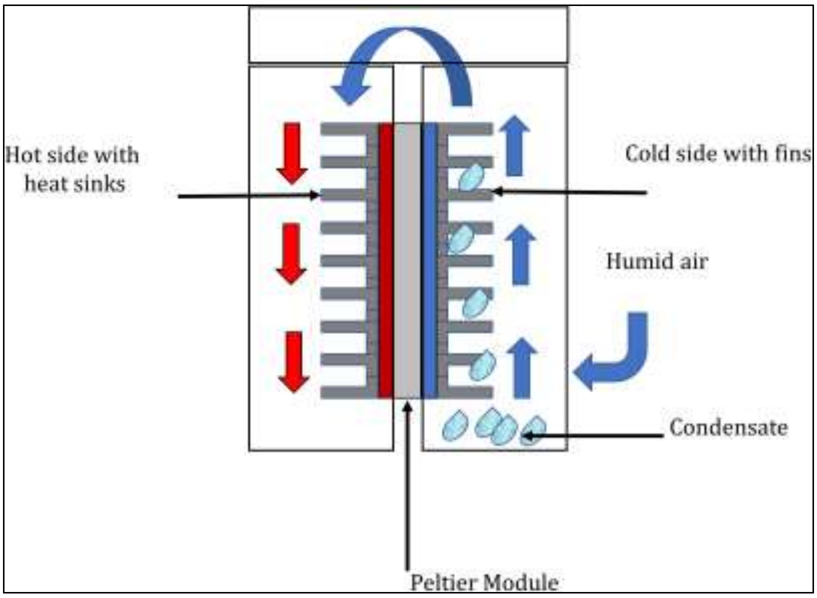

Fig 2: Thermoelectric cooling-based AWG system

In principle, AWGs extract water molecules from air, causing a phase change from vapor to liquid. This is done by decreasing the temp. of air till dew point temperature and converts atmospheric moisture directly into clean drinking water form by condensing the latent heat of water vapour into water droplets. Under constant atmospheric pressure, the dew point depends only on the Relative Humidity (RH) and the Ambient Temperature. However, their main drawback is the high power consumption. This paper presents the optimization process of an Atmospheric Water Generator (AWG) based on a thermometric cooler or Peltier Effect that is self-sustained using renewable energy. The working of the peltier module is based on the peltier effect proposed by Jean-Charles Peltier, a French Physicist in 1834.

The Concept of an AWG based on TEC is being shown in the block diagram of overall system The study domain is covered by a dash line that consist of the PWM controller circuit and air fan, an array of Peltier modules, the hot side channel as radiator, the blade valve to control hot air flowed into the condenser and the cold side channel as a condenser.

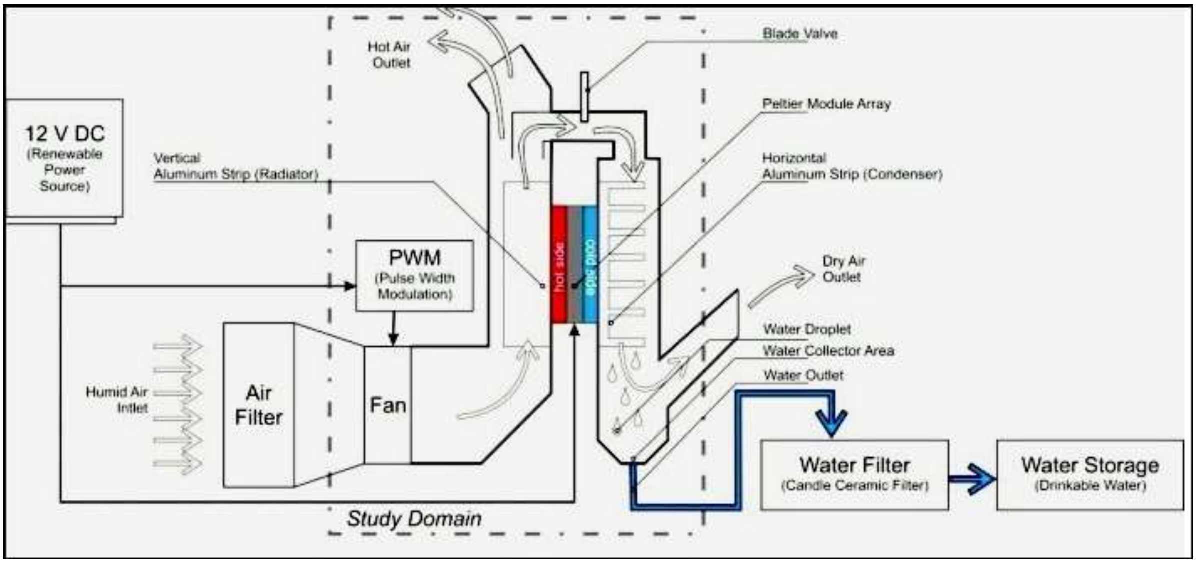

Fig 3: The Block Diagram of the AWG Device Based On TEC

The TEC transforms electric energy into a temperature difference by the thermoelectric cooling effect, which consists of heat transfer from the cool side to the hot one. This heat transfer has been optimized by the use of heat sinks on both sides of the cooler. The inside heat sink will be referred to as the water condenser element because the water vapor condensation takes place in this heat sink, and the system composed of the TEC and its heat sinks will be referred to as the extended TEC.

The Solar panel acts as a source for charging the 12V battery to ensure constant functioning of the AWG. As we supply current through the battery to the peltier module, heat is evolved at the upper junction & adsorbed at the lower junction & therefore the upper side gets hot & the lower side gets cooled. After some time as we reach the dew point temperature the condensation starts or moisture and soon after this moisture is converted into water droplets this can be collected in the container.

Literature review

In this paper the, atmospheric water generation technologies using peltier effect are reviewed. And mainly focused on AWG using Peltier cooler device, Solar driven AWG and variation in airflow and input current to the AWG system. By considering all the parameters and climatic conditions, the AWG should build to produce optimum yield.

1. Salehi, Ghannadi-Maragheh, Torab-Mostaedi, Torkaman, & Asadollahzadeh, 2020: The amount of earth's water is constant, and it circulates in a closed loop. In addition, just 3% of all earth water is potable for human utilization in farming, industries, cities, and households. polar ice contains almost three quarter of the earth's drinkable water and human cannot use it, as a result, just a small proportion of the world's water is used by humans.
2. M. Kumar, Yadav, & Mehla, 2019; The three most fundamental requirements for human existence are shelter, clothing, and nourishment. For the first two needs, there are numerous alternatives, but the third is extremely important and has relatively few alternatives. The food must be clean since water is the most important component of the food because it is needed for drinking, cooking, and cleaning.
3. Li *et al*., 2018: Fog collecting is the oldest method of collecting water droplets that are floating in the atmosphere. Moreover, because this technique requires a continual high atmospheric relative humidity (RH) (100 percent), it is only practicable in a few places.
4. M.Eslami *et al*. presented an experimental study of Thermal analysis and optimization of a system for water harvesting from humid air using thermoelectric coolers. They have used sensitivity analysis to find the optimum number of TECs. The resulting system is capable of producing 26 ml of water within 1 h from the air with 75% relative humidity and the temperature of 318 K by consuming only 20 W of electrical power.
5. Shanshan liua *et al*. presented an experimental analysis of portable atmospheric water generator by thermoelectric cooling method. The experimental system contained a humidifier, a mixing chamber, an air channel and a TE water generator with 2 TECs. The resulting system can able to generate 25.1 g per hour with the usage of 58.2 W input. This system is suitable for outdoor use.
6. Jatin Patel *et al*. presented an experimental investigations of atmospheric water extraction device under different climatic conditions. This system works on vapour compression refrigeration cycle. This system can capable of extracting 0.28 L/h in mild and dry condition and up to 1.78 L/h in humid and warm condition. According to this study AWE devices are most effective in hot and humid regions.
7. Kashif Irshad *et al*. presented an experimental study of a thermoelectric air duct dehumidification system for tropical climate. This system consists of 24 TEMs connected with airduct dehumidifier and it is called TE-ADD system. TE-ADD system is connected to an air-conditioning test chamber under tropical conditions of Perak, Malaysia and investigated. According to numerical method analysis with ±6% error the optimal production is achieved for an input current of 3 A to 4 A at an airflow rate of 0.012 kg/s, while that for an input current of 5A to 6 A is achieved at 0.011 kg/s.
8. Lauren Sharpe *et al*. presented a study of how to increase the efficiency of a peltier device by assessing the thermal performance of liquid cooled microchannel

heat sinks. Liquid cooled heat sinks were used in this system so that it can provide highest thermal efficiency. They investigated for suitable coolant for the microchannel heat sinks with water, Al_2O_3 nanofluid, TiO_3/H_2O nanofluid, Nanofluid, Trans critical CO_2, Supercritical CO_2 and Galinstan. At the end they selected Galinstan as it requires low pumping power to achieve its minimal thermal resistance and due to its great cooling ability.

9. Dr. G. Satish Pandian *et al*. proposed a review on design and fabrication of atmospheric water generator using peltier effect. Their main aim is to build a AWG to produce fresh drinking water with high coefficient of performance. After obtaining dew point temperature they calculated COP of peltier, so that they can estimate time required to generate water droplet.
10. Vivek Patel *et al*. presented an experimental and theoretical study on the influence of thermo-electric cooling dehumidifier on humidification-dehumidification water desalination system. Theoretically it was explained as (Energy at dehumidifier inlet) = (Energy absorbed by TEC modules) + (Energy carried away by distilled water) + (Energy at dehumidifier outlet air) and experimentally it was done in 3 set by varying mass flow rate, air temperature and relative humidity.
11. Chana Uttasilp *et al*. presented a study on optimal solar energy on thermoelectric cooler of water generator in case study on flood crisis. The prototype was built and tested at temperature around 30 degree C and humidity was in the range of 60-80%. The results shows that 0.2-0.3L of drinking water per day with power consumption of 2.5-3.6 W.
12. Ali Akbar Salehi *et al*. presented a review on the water-energy nexus for drinking water production from humid air. They proposed that use of renewable energy is the solution for reduction of energy costs. And they proposed that water can be harvested with the technologies like nature structure, fog collection, underground selection, atmospheric water generators and absorption method.
13. Du Runze *et al*. presented an experimental investigation on a portable atmospheric water generator for maritime rescue. The system composed of a water generating module, a water purifying module, a power supply and control module and a buoyancy module. The results showed that the best water production rate of 460 mL/h was achieved when Tin =27 and RHin=92%.
14. Atul Ekad *et al*. presented a study on solar powered atmospheric water generator and overview on AWG technologies. They compared two different technologies, like vapour compression system which can only produce 72.1 ml of water per KW-hr and AWG with peltier effect can produce 1L of water per hour at high humid conditions.
15. Rang Tu *et al*. presented a study on reviews of atmospheric water harvesting technologies. They are condensation technology, sorption technology and other technologies. And compared among each of the technologies to choose the best one. They concluded that condensation technology with TEC can produce the average of 1.71 kg/hr.
16. Rohan Gupta *et al*. presented a study on Water through air using peltier elements. This conventional cooling system contains three fundamental parts- the evaporator, compressor and condenser. The TE couples are combined in a module and connected electrically in series and thermally in parallel to obtain a promising output. The resultant system can generate 1L of water per hour in humid regions at daytime.
17. Hasila Jarimi *et al*. presented a study on review of sustainable methods for atmospheric water harvesting. They proposed reviews about atmospheric fog harvesting and dew water harvesting including different varieties. They concluded that desiccant based water collection systems are sophisticated than radiation-based systems but can collect more water.
18. Kiara Pontious *et al*. presented an experimental study on design of an atmospheric water generator harvesting water out of thin air. They built two prototypes, one with cross flow heat exchanger and another with thermoelectric cooler. These prototypes were built to operate under dry bulb temperature range of 55– 130-degree F and RH range between 52%-100%. As performance wise both the protypes were performed well. They proposed that these technologies can be used for agricultural irrigation instead of desalination technology.
19. Du Runze *et al*. Authors here are using AWG to help people in distress in seas (South China Sea). People in distress who may need rescue must hold onto their lives as long as possible before the search party arrives, there the use of portable seawater desalinations device proves effective. The researchers designed a AWG which had a water generating module, water purifying module, power supply and a buoyancy module which gave them 5.52L/d with temperature being 27C and RH being 92% and desalination rate above 96% which is proved as a feasible solution for the people in distress.
20. Thualfaqir J. *et al*. The researchers built a prototype of AWG. The prototype was solar powered and portable with a peltier module which was attached with fans on both ends of the module. They wanted to increase the generation of water from the proposed AWG. They experimented this by increasing the air flow rate at the hotter side of the peltier module. The prototype was generating about 9.5ml/hr. at airflow velocity of 1m/s, but after increasing the air flow rate at the hotter side the peltier module the water generated was increased to 20 ml/hr. at the same airflow velocity i.e., 1m/s.
21. Soroush Moradi *et al*. The author gave almost prominence in understanding the existing active and passive type of AWG’s and their advantages and disadvantages, and from that data he is designing a new model which deals with some obstacles these existing AWGs are facing. He compared the model which works with the help of external power supply(active) which generates good amount of water but has a problem while installing in remote areas or forests where regular service isn’t available and a model which collects water from dew and fog(passive) where in this case service isn’t needed often but collection of water collected is very much lesser. Thus, the author proposing a new design where the funnel shaped condenser tilted at 60 degree with additional edges at the bottom will be more efficient than the existing models

Methodology

Calculations shall based on the parameters given below collected from the Indian climate site belongs to Jabalpur (M.P.) The below climatic parameters of Jabalpur (M.P.) has been collected from the www.indianclimate.com, shows the average values of various meteorological parameters over the year in Jabalpur ((lat: 23°10'0"N, lon: 79°58'60"E) The average wind speed in Jabalpur is 2.8 m/s with the maximum wind speed of around 10 m/s. The average ambient temperature remains 25.3 °C, varies from 5.7 °C to 43.9 °C. The average relative humidity remains around 59.4%, varies from 10.5% to 99.2%. The station pressure varies from 954 hPa to 941 hPa, averaged around 968 hPa.

Table 1: Meteorological Data Summery of Jabalpur

Meteorological Data Summary of Jabalpur			
Parameter	Min	Max	Avg
Wind Speed m/s	N/A	9.7	2.8
Temperature °C	5.7	43.9	25.3
Dew Point °C	1	27.1	15.4
Humidity %	10.5	99.2	59.4
Pressure hPa	940.8	967.8	954.4

Table 2: The table below shows the minimum, maximum and average % Relative Humidity over the year in Jabalpur.

Parameter	Relative Humidity, %			
	Minimum	Maximum	Average	Standard Deviation
January	23.4	90	55.9	± 15.0
February	23.7	95.5	56	± 17.8
March	10.5	72.1	36.9	± 13.3
April	12.9	78.8	33.2	± 13.3
May	13.9	54.5	30.7	± 9.4
June	25.6	98.3	59.2	± 17.8
July	59.1	99.1	87.7	± 8.1
August	68.9	99	89.6	± 6.0
September	41.6	99.2	79.7	± 13.5
October	33.3	87.9	60.1	± 12.9
November	28.4	85.4	60.5	± 13.4
December	29.5	90.8	62.5	± 14.2

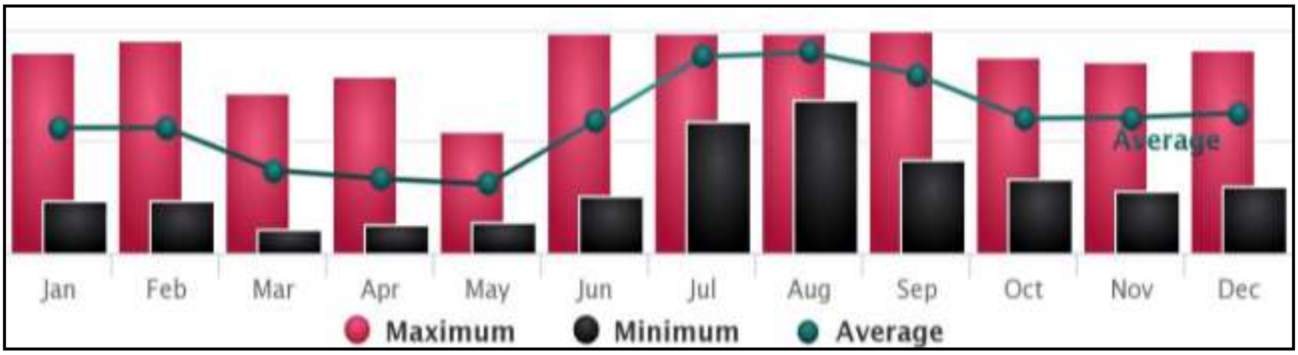

Fig 1: Monthly Relative Humidity Data of Jabalpur

Table 3: Meteorological Data Summary of Jabalpur

Parameter	Min	Max	Avg
Wind Speed m/s	N/A	9.7	2.8
Temperature °C	5.7	43.9	25.3
Dew Point °C	1	27.1	15.4
Humidity %	10.5	99.2	59.4
Pressure hPa	940.8	967.8	954.4

Table 4: The table below shows the minimum, maximum and average °C Temperature over the year in Jabalpur.

Parameter	Temperature, °C			
	Minimum	Maximum	Average	Standard Deviation
January	8.1	27	16.6	± 4.9
February	13.4	31.6	21.2	± 4.6
March	17.8	37.4	26.7	± 4.8
April	23.4	39.9	31	± 4.5
May	26.9	43.9	35.1	± 4.0
June	23.4	39.8	31.1	± 3.7
July	22.1	32	26.4	± 1.9
August	22.7	30.7	25.8	± 1.5
September	22.4	32.8	26	± 2.6
October	18.2	33.6	25.9	± 3.8
November	13.4	31	21.7	± 4.4
December	5.7	24.2	16.1	± 4.4

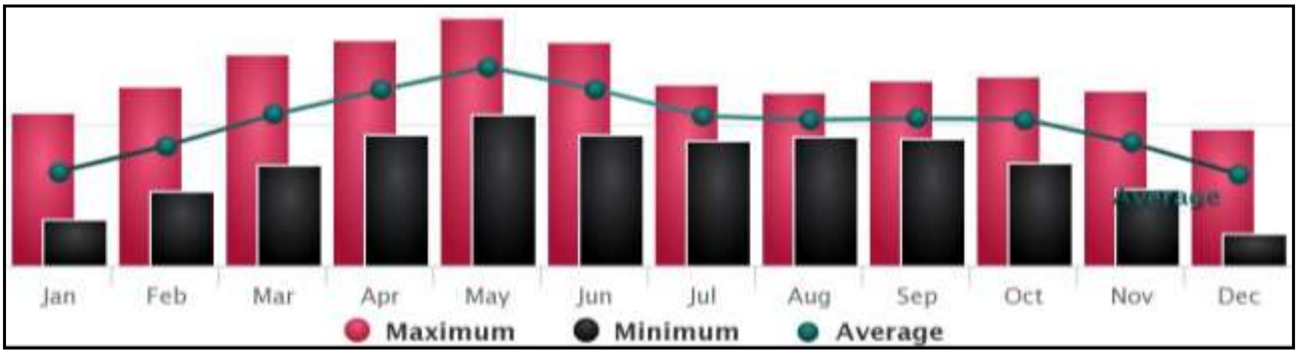

Fig 2: Monthly Temperature Data of Jabalpur

Theoretical calculation

In order to determine the required dew point temperature at different temperature and relative humidity, the following equations offer the required dew point temperature for water vapour condensation using the Magnus formula.

Dew-point temperature 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. A well-known approximation used to calculate the dew point, Tdp, given just the actual("dry bulb") air temperature, T and relative humidity (in percent), RH, is the “Magnus formula”.

γ(T, RH) = ln (RH/100) +Bt/c + T

Tdp =cγ(T, RH)/b − γ(T, RH)

(Where, b = 17.67 & c = 243.5 °C and T is in °C)

The above formulas is used to calculate the dew point temperature for different atmospheric conditions at which the device may be subjected to operate.

Sample Calculations

γ= ln (57/100) +17.67*33/243.5*33 =1.546 Tdp =(243.5*1.546)/(17.67-1.546) = 23.35 °C

Amount of water (in L) present in 1m3 of air

Humidity Ratio gives the volume of water (in m3) present in 1m3 of air.

Partial Pressure of water (Pw) = $RH \div 100 \times P$

Humidity Ratio = $0.622 \times Pw \div Pa - Pw$

(Where Pa is the atmospheric pressure i.e. Pa=1.01325 bar)

Humidity ratio gives the amount of water (in m3) present in 1m3 of air. Also we know that 1m3 is equal to 1000 litres. Thus multiplying humidity ratio by 1000 gives the maximum amount of water (in litres) that is present in 1m3 of air.

Sample Calculations (For atmospheric temperature 30 °C and relative humidity 50%)

Saturation Pressure of water vapour (Pw) at 30 °C is obtained from steam table as 0.04241 bar.

Pw = (50÷100) × 0.04241 = 0.021205bar

Humidity Ratio= 0.622 × 0.021205÷ (1.01325-0.021205) = 0.013295273

Therefore amount of water (in litres) present in 1m3 of atmospheric air

= Humidity ratio × 1000 =

0.013295273× 1000 =

13.2952739 litres

However, when it comes to calculating the unit energy, following parameters are considered and used.

Ue = $(Pel\ \Delta T)/100\ w$

Where

Ue = unit energy per letter (KJ/L)

Pe = power consumption (W)

ΔT = time in second

W= water productivity (L/day)

Following Estimated Data obtained in order to get the proposed system performance has been compiled & tabulated to illustrate the estimated results of how much water shall be generated from proposed system.

Number of Data Considered for Each Two hours	Data Considered Hours	Ambient Temperature	Relative Humidity	Amount of Water
1	2 Hours	20	50	7.31 g/kg
2	2 Hours	25	55	10.98 g/kg
3	2 Hours	30	60	16.36 g/kg
4	2 Hours	35	65	24.21 g/kg
5	2 Hours	40	70	35.61 g/kg
6	2 Hours	45	75	52.11 g/kg

Calculated the amount of water in one day right from 6.00 AM to 6 PM (during 12 hours per day) at different temperature and relative humidity for 2 hours respectively will be as below:

01. 7.31 g/kg X 12 Hrs = 87.72
02. 10.98 g/kg X 12 Hrs = 131.76
03. 16.36 g/kg X 12 Hrs = 196.32
04. 24.21 g/kg X 12 Hrs = 290.52
05. 35.61 g/kg X 12 Hrs = 427.32
06. 52.11 g/kg X 12 Hrs = 625.32

Average 293 gm/kg or we may presume that there is 293 gram of water is available per kg of air under the climate condition of Jabalpur. We also observed that with increase in temperature and humidity the water content also increased.

Conclusions

The authors suggests that the Thermo-electric Cooling method is simplest and most straightforward approach to harvest and extract water from atmosphere under the climatic condition of Jabalpur. This overview indicates that this Atmospheric Water Generator (AWG) is still in its earlier stages, giving immense scope for further exploration In this paper the AWG based on TEC principle and its importance has given the current concerns regarding local as well as global water scarcity. This AWS device for extracting water from the atmosphere based on the TEC Principle could be a very useful device to meet future potable water needs both at local and global level.

Future Scope and Conclusion

A solar energy powered AWG system is consisting of/constructed with a TE cooler, solar panels, a heat exchange unit, and a Pulse with modulation (PWM)/digital control device. The technology is self-powered and may be utilized to produce water from the surrounding humid air. The primary motivation is to create a system that could generate clean potable drinking water from air. Before beginning the practical investigation, we estimated the predicted output from air analytically. At the time, the outcome was very gratifying. Because the energy source is free and the solar system normally requires less care, this system would be a long-term, cost effective solution. The development and production of such equipment is a future commercial possibility.

References

1. Jackson RB, Carpenter SR, Dahm CN, McKnight DM, Naiman RJ, Postel SL, Running SW. Water in a changing world. Ecological applications. 2001 Aug;11(4):1027-1045.
2. Zhang P, Li J, Lv L, Zhao Y, Qu L. Vertically aligned graphene sheets membrane for highly efficient solar thermal generation of clean water. ACS nano. 2017 May 23;11(5):5087-5093.
3. Gao M, Zhu L, Peh CK, Ho GW. Solar absorber material and system designs for photothermal water vaporization towards clean water and energy production. Energy & Environmental Science. 2019;12(3):841-864.
4. Delpla I, Jung AV, Baures E, Clement M, Thomas O. Impacts of climate change on surface water quality in relation to drinking water production. Environment international. 2009 Nov 1;35(8):1225-1233.
5. Kim H, Yang S, Rao SR, Narayanan S, Kapustin EA, Furukawa H, Umans AS, Yaghi OM, Wang EN. Water harvesting from air with metal-organic frameworks powered by natural sunlight. Science. 2017 Apr 28;356(6336):430-434.
6. Das R, Ali ME, Abd Hamid SB, Ramakrishna S, Chowdhury ZZ. Carbon nanotube membranes for water purification: A bright future in water desalination. Desalination. 2014 Mar 3;336:97-109.