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Making Water from Air

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Abstract:

The aim of the project is to create a portable device that can be used to meet the water requirements of a regular household. The device will first condense water present in the atmosphere and then purify it so that it can be used for drinking. The design should maximize the water produced per unit energy. The design should minimize the cost per unit water production for both capital cost and production cost. In this application we seek to harness this water from the atmosphere and utilize it for drinking.

I. INTRODUCTION:

While designing the atmospheric water generator it was identified that three requirements were necessary to ensure that the final project would effectively fulfill its intended purpose.
They are:

- Portability of Water - Water produced by the design must conform to the World Health Organization (WHO) drinking water quality standards.
- Simplicity of Use - Design must be operable by persons of limited technical experience.
- Safety - Design must not pose a hazard to users at any point during its normal operation.

We developed several goals that the design should be able to meet. They are-

- Flexibility in Power Source - The design should be able to utilize a variety of power sources, including (but not limited to) solar, wind, and the traditional power grid. .
- Maximize Efficiency - The design should maximize the water produced per unit energy.
- Minimize Cost - The design should minimize the cost per unit water production for both capital cost and production cost.

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Dehumidification Techniques:

When approaching the problem of atmospheric water generation the first step is to analyse different methods of dehumidification. In this application we seek to harness this water from the atmosphere and utilize it for drinking. Three common psychometric methods of dehumidification stood out during preliminary research; a temperature drop below the dew point (refrigeration condensing), pressure condensing, or a combination of the two. Along with this wet desiccation technique can also be used for the above purpose. Each of these techniques are discussed below:

Dehumidification by Refrigeration:

Traditional refrigeration cycle dehumidification remains the most prevalent method for generating water from atmospheric humidity. This method circulates air over cooling coils connected in a refrigeration cycle to bring the water in the air below its dew point. The dew point of the water is dependent on the vapor pressure and humidity and tends to be a relatively low temperature compared to the ambient conditions. To reach the dew point the air running through the unit will have to be cooled a considerable amount. This approach is expressed in Figure 1 below

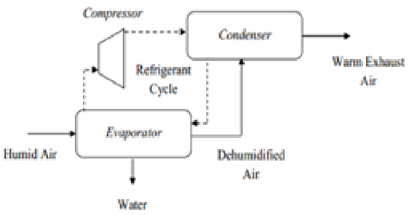

Figure 1: Dehumidification by Refrigeration cycle.

Refrigeration can be achieved by many methods. Some of these are discussed below:

Vapour Compression Method:

Vapour-compression refrigeration is the most widely used method for air-conditioning in today's world. The vapour-compression consists of a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat to the atmosphere.

Figure 2 depicts a single-stage vapour-compression system. Basically the system has four components: a compressor, a condenser, a thermal expansion valve and an evaporator. Circulating refrigerant enters the compressor as saturated vapour and is compressed [1]. This results in high pressure which in turn is responsible for higher temperature.

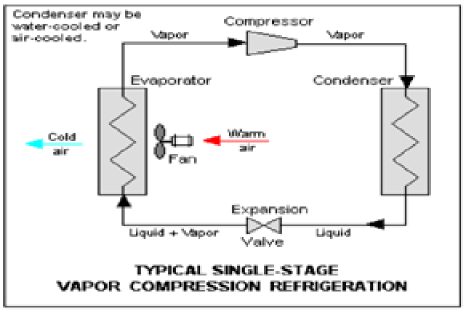

Figure 2: Vapour Compression Refrigeration cycle.

Refrigerant:

After the introduction of the Montreal Protocol in the year 1987 all the parties agreed to phase out the dangerous ozone depleting refrigerants like CFCs which is one of the most crucial item of a vapour compression refrigeration system. Thus there is a gradual shift from the CFCs to the HCFCs with the motive of saving our ozone layer. Now a days a lot of research is being carried out to explore environment friendly refrigerants, supercritical carbon dioxide known as R-744 [3] being one of them, which have same efficiencies as compared to existing CFC and HFC based refrigerants, and have many orders of magnitude lower global warming potential.

3) Types of gas compressors:

The various types of compressors used are reciprocating, rotary screw, centrifugal, and scroll compressors. Each of these types has their respective application based on their size, noise, and efficiency and pressure ratings. Generally compressors are of three types. They are - open, hermetic, or semi-hermetic, depending on the position of the compressor and/or motor in relation to the refrigerant being compressed. The following configurations maybe achieved:

- Hermetic motor + hermetic compressor
- Hermetic motor + semi-hermetic compressor
- Open motor (belt driven or close coupled) + hermetic compressor
- Open motor (belt driven or close coupled) + semi-hermetic compressor

In most of the hermetic, and semi-hermetic compressors, the compressor and motor driving the compressor are integrated. The refrigerant being compressed during operation itself cools the hermetic motor. The obvious disadvantage being the motor is integral with that of compressor and in case of any failure in the motor it cannot be removed and repaired. Further the burnt out windings may contaminate the whole refrigeration system requiring the system to be entirely pumped down and replacement of the refrigerant [4]. An open compressor consists of a motor drive which is placed outside of the refrigeration system, and an input shaft is used to provide drive to the compressor which are sealed with the help of gland seals. Generally the open compressor motors are air-cooled and can be fairly easily exchanged or repaired without degassing of the refrigeration system. The disadvantage of this type of compressor is loss of refrigerant due to failure of gland seals. Easy cooling and simple design makes the open motor compressors more reliable in case of high pressure applications where compressed gas temperatures can be very high. However the use of liquid injection for additional cooling can generally overcome this issue in most hermetic motor compressors.

II. PELTIER COOLING:

This method is exactly same as that of Vapour Compression Refrigeration method but here we use a Peltier device to achieve the required dew point temperature. Peltier device is compact, has less moving parts, is energy efficient and has a very long life span which requires very less maintenance.

1) Principle of Peltier Device

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other, with consumption of electrical energy, depending on the direction of the current. Such an instrument is also called a Peltier device, Peltier heat pump, solid state refrigerator, or thermoelectric cooler (TEC) [5]. It is possible to compress humid air so much that it will condense at the ambient temperature. As pressure increases the dew point rises; thus, enough compression will force the dew point above the ambient temperature resulting in spontaneous condensation; heat will transfer from the pressurized humid air to the ambient air. Compressing air to extract water could potentially require pressures up to five times the ambient pressure.

This will require a very sturdy tank that can handle high amounts of stress in its walls. This method has great potential for low energy demands, especially if one was able to recapture some of the energy in the compressed air using a turbine or piston. The energy efficiency of this design option has great promise but it is heavily dependent on compressor and decompressor efficiency and humidity. The primary advantage of pressure dehumidification is the low energy requirement; the only unavoidable loss is the pressure applied to the water vapour. However, any inefficiency in the compression/decompression cycle is amplified by the large volume of air processed per unit water produced. Additionally, the rate of production when driven by natural convection cooling to the atmosphere is too slow for significant production; some mechanism to speed up this heat transfer needs to be implemented, increasing the energy cost. No existing atmospheric water generators utilize this approach.

Dehumidification by liquid desiccant method

A desiccant is a hygroscopic substance that induces or sustains a state of dryness (desiccation) in its vicinity.

Commonly encountered pre-packaged desiccants are solids that absorb water. Wet desiccation is a process where a brine solution is exposed to humid air in order to absorb water vapour from that air. The solution is then sent into a regenerator where the water vapour is extracted from the solution 2. This method has grown in popularity because of its efficiency and the ease with which it can be adapted to renewable energy, particularly solar. Figure 3 below is a basic representation of this approach. A primary advantage to this approach is that the desiccant accomplishes the most difficult part of dehumidification, extracting the water from the air, without a direct expenditure of energy. The problem is thus recast into terms of regenerating the desiccant and capturing the resultant water. The main disadvantage of wet desiccation is the complexity that is introduced, both in terms of system and materials.

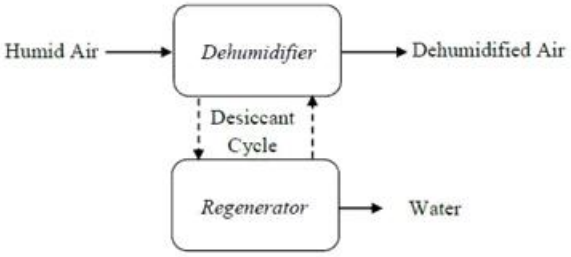

Figure 3: Dehumidification by desiccation.

Filtration Unit:

The water obtained from the device after condensation is not fit for drinking. It contains a lot of germs and harmful bacteria which may cause diseases. Also it contains suspended particles which need to be filtered out. This can be achieved by first passing the condensed water through activated carbon filter. Then it is subjected to UV light so as to kill the harmful microbes.

III. CALCULATIONS:

Dew point temperature calculation

Definitions:

Dew-point temperature (Tdp) 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.

Dry-bulb temperature (DBT) is the temperature of air measured by a thermometer freelyexposed to the air but shielded from radiation and moisture. DBT is the temperature that is usually thought of as air temperature, and it is the true thermodynamic temperature.

Relative humidity (RH) is the ratio of the partial pressure of water vapour to the equilibriumvapour pressure of water at the same temperature. The dew point is the saturation temperature for water in air. The dew point 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 with water. When the moisture content remains constant and temperature increases, relative humidity decreases. [9] This calculation forms an important part of this project as this helps us to determine at temperature the Peltier device must be maintained in order to condense the humidity present in air at the given atmospheric condition. 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:

$$\gamma(T,RH) = ln\left(\frac{RH}{100}\right) + \frac{bT}{c+T}$$

$$T_{dp} = \frac{c\gamma(T,RH)}{b-\gamma(T,RH)}$$

(Where, b = 17.67 & c = 243.50C and T is in 0C)
The above formula is used to calculate the dew point temperature for different atmospheric conditions at which the device may be subjected to operate. With the help of Microsoft excel the operating parameters are calculated and tabulated.

Sample Calculations:

(for DBT=30°c and RH=45%)

$$\gamma(30{,}45) = ln\left(\frac{45}{100}\right) + \frac{17.67 \times 30}{243.5 + 30} = 1.139$$

$$T_{dp} = \frac{243.5 \times 1.139}{17.67 - 1.139} = 16.77735769$$

The table for the dew point temperature calculation for different atmospheric conditions is as follows:

Table 1: Dew point temperature calculations at 30°C and different relative humidityConditions.

Dry Bulb Temp. (in °C)	Relative Humidity (%)	Required Dew point Temp. (in °C)
30	45	16.77735769
30	50	18.46356201
30	55	19.99121587
30	60	21.40183613
30	65	22.71309952
30	70	23.93889215
30	75	25.09032956
30	80	26.17645367
30	85	27.20472258
30	90	28.18136311
30	95	29.11163002
30	100	30

Amount of water (in L) present in 1m³ of air for different humidity andtemperature conditions.

Definitions:

Saturation Pressure (Ps) is the pressure of a vapour which is in equilibrium with its liquid (assteam with water) i.e. the maximum pressure possible by water vapour at a given temperature. The saturation pressure of water at different atmospheric temperature is obtained from the commercially available steam tables. Air is a mixture of both air molecules and water molecules. Partial Pressure of water (Pw) is the pressure of water vapour present in a mixture of air and water vapour.

Relative Humidity (RH) is the ratio of partial pressure of water (Pw) to that of saturation pressure(Ps) i.e.

$$RH = \frac{P_w}{P_s} \times 100$$

Thus from saturation pressure (Ps) and relative humidity (RH) data partial pressure of water (Pw) can be obtained as

$$P_w = \frac{RH}{100} \times P_s$$

Humidity Ratiogives the volume of water (in m^3) present in 1m^{3}of air. Humidity ratio can also be expressed in terms of partial pressure of water (Pw) as

$$Humidity\ Ratio = 0.622 \times \frac{P_w}{P_a - P_w}$$

(Where Pa is the atmospheric pressure i.e. Pa=1.01325 bar) Humidity ratio gives the amount of water (in m^3) present in 1m^3 of air. Also we know that 1m^3 is equal to 1000 litres. Thus multiplying humidity ratio by 1000 gives the maximum amount of water (in litres) that is present in 1m^3 of air.

Sample Calculations

(For atmospheric temperature 25°C and relative humidity 35%) Saturation Pressure of water vapour (Pw) at 25°C is obtained from steam table as 0.03167 bar.

Thus Partial pressure of water, $P_w = \frac{RH}{100} \times P_s = \frac{35}{100} \times 0.03167 = 0.0110845$ bar

Humidity Ratio $= 0.622 \times \frac{P_w}{P_a - P_w} = 0.622 \times \frac{0.0110845}{1.01325 - 0.0110845} = 0.006879661$

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Therefore amount of water (in liters) present in 1m^3 of atmospheric air = × 1000 = 0.006879661 × 1000 = 6.879661 liters

IV. ANSYS (FLUENT) ANALYSIS

Different steps which were followed for the analysis are given below:

Geometry

First the model is imported to ANSYS workbench.

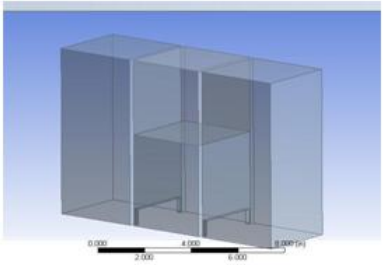


Figure 4: Geometry import in Fluent.

Meshing

Then meshing is done

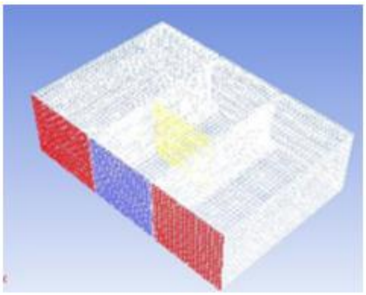
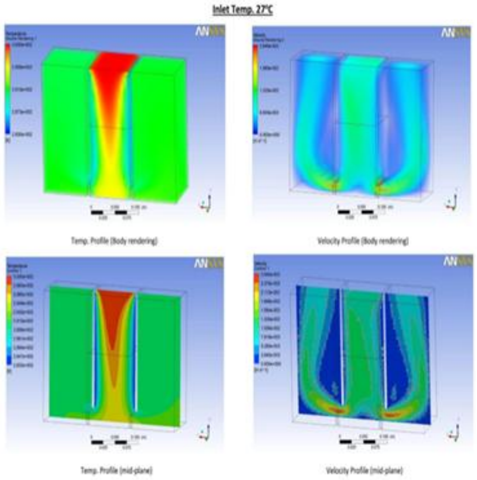


Figure 5: Mesh Generation



Inlet Temp. 27°C

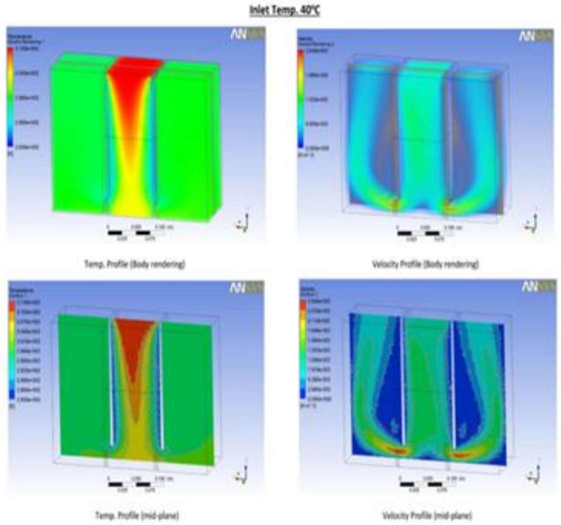
Temp. Profile (Body rendering)

Velocity Profile (Body rendering)

Temp. Profile (mid-plane)

Velocity Profile (mid-plane)

Fig 6: ANSYS result inlet temperature 27 deg



Inlet Temp. 40°C

Temp. Profile (Body rendering)

Velocity Profile (Body rendering)

Temp. Profile (mid-plane)

Velocity Profile (mid-plane)

Fig 7: ANSYS result inlet temperature 40 deg

V. DISCUSSION OF CALCULATIONS AND RESULTS

After carrying out various calculations the results obtained are tallied and analyzed. Earlier we had calculated the dew point temperatures required for different atmospheric conditions. Tables 1 shows the results obtained. Then we calculated the least temperatures that can be obtained from our device by specifying the boundary conditions in FLUENT workbench. The conclusions are:

1. For inlet air temperature 30^{o}C the temperature of air in the device drops down to that of 293 K or 20^{o}C. Table 1 show that for temperature 30^{o}C the dew point temperature is greater than 20^{o}C for relative humidity 60% or higher. Thus it is clear that if atmospheric temperature is 30^{0}C and relative humidity is greater than 60% then the device will start condensing water.
2. For inlet air temperature 40^{o}C the temperature of air in the device drops down to that of 298 K or 25^{o}C. Table 3 shows that for temperature 40^{o}C the dew point temperature is greater than 25^{o}C for relative humidity 45% or higher. Thus it is clear that if atmospheric temperature is 40^{o}C and relative humidity is greater than 45% then the device will start condensing water.

From all the above inferences we can finally conclude that if ambient temperature is 35°C or higher and if relative humidity is greater than 50% then the device will function well and it will start condensing water.

Fig 8: working model proposed project

VI. CONCLUSION:

The prototype was subjected to tests at Hyderabad and it was found that the water output from the device was not satisfactory. After diligent study and research we found that the following reasons may be responsible for the low water output of the device:

1. The tests were done in Hyderabad which is a region with low humidity. And based on our calculation the humidity of a region must remain above 50% for proper functioning of the device. So we expect that the water output may increase if the device is tested in coastal areas where the humidity is high.
2. As such the cold surface area of the Peltier device is very less (4cm*4cm). So we used a copper plate in contact with the cooling surface of the Peltier device because of its high conductivity expecting that the cold surface area will increase thereby increasing the condensation area. But finally in the prototype when we used the copper plate proper thermal contact between the cold Peltier surface and the copper plate could not be achieved. This maybe the possible reason for low efficiency.
3. On running the device, initially condensation started and water droplets were formed on the cold surface of the Peltier device. But subsequently due to the deposition of these water droplets the thermal conductivity of the region decreased as water is not a good thermal conductor. Hence the condensation process slowed down subsequently.
   In order to increase the output in the future, a wiping mechanism may be incorporated in the device so as to increase the condensation rate.
4. Presently, we have used only two Peltier devices in the prototype. In the future the prototype may incorporate another two Peltier devices so as to increase the water output.

For giving the prototype an environmental friendly flavor it may include a solar power source (solar panel) in place of the present AC power source without much modification in the circuitry.

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