Extracting Water and Energy from the Air: A Quantitative Study

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Abstract

The main goal of the study is to design, prototype, and test an effective water collection system that will condense humidity in the atmosphere and convert it into liquid water. This has dual benefits. The stored water can be used for drinking or other purposes especially in water-poor regions or in developing countries. Another potential benefit which will be tested and quantified is that the stored water could be turned into electricity in combination with a fuel cell, therefore using all or part of the collected water to generate electricity. To test this hypothesis, a prototype was constructed to provoke the formation of condensation so that it could be collected. These water molecules are then split using electrolysis to harvest the hydrogen and oxygen for a hydrogen fuel cell. This fuel cell is what will produce electricity, which is the overall output for the system. To make this system utterly passive, the electrolyzer is powered by a solar panel to carry out the splitting of the water molecules.

1. Background

Running water and electricity are two resources most of us take for granted. Still, there are billions of people across the globe who do not have access to these basic, yet vital resources. Moisture naturally found in our atmosphere is a widely untapped resource we can benefit from. Even in arid climatic conditions or in deserts, condensation collection techniques have been shown to get upwards of 200 gallons of water per day through various engineered systems for water condensation and collection. Such designs are passive and do not require any input once they are built or placed on site. Biomimicry, or design principles inspired from nature, are often used in the development of such collection systems. Other than providing drinking water, this amount of water holds enough energy to provide electricity to fuel peoples basic needs in their homes by use of a fuel cell.

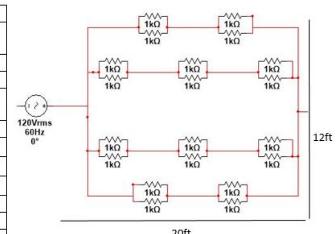
2. Introduction

Condensation is a method of extracting water from air. It involves pressure or temperature changes to the air which causes water vapor to stick to a surface. As the temperature and/or pressure of the air increases, the likelihood that water will condense on a surface increases. This physical phenomena can be exploited by developing a system which either increases the temperature or pressure of the air. In this case, a box with a transparent roof that will allow the sun to heat the inside. The condensate is then collected and put through an electrolyzer, which uses an electrical current to cause the water molecules to split into hydrogen and oxygen. This electrolyzer is powered by a solar panel, which has a type of material that converts photons into an electrical current. Once the water is decomposed, the byproducts can be fed into the hydrogen fuel cell.

A fuel cell is a device that converts chemical energy into electricity through a chemical reaction that involves oxygen. Fuel cells are able to produce electricity cleanly by using hydrogen and oxygen as a fuel, their only byproduct being water vapor. Since fossil fuels are not combusted as part of the process, fuel cells are a renewable way of generating electricity. Fuel cells are a relatively new technology. Due to problems with system efficiencies and related costs they are more suited toward small scale applications as compared to utility level installations.

Before any designing or prototyping, research was carried out to test the feasibility of creating electricity from the air. To fully understand this, a calculation was done which finds how long such a system would be able to power the lights in a typical classroom assuming 100% efficiency of collecting electrons from the hydrogen atoms in water. The assumed wiring diagram of the classroom and calculations are shown in Figure 1.

Temperature	26.7	°C
Absolute Humidity (Saturated)	22.2223	g/kg
Assume:		
Relative Humidity	60	%
Absolute Humidity (Actual)	13.33338	g/kg
Density of Air	1.225	kg/m^3
Approximate Volume	2160	ft^3
	61.16	m^3
Amount of Air	74.93	kg
Amount of Water	999.022	g
Molar Mass of Water	18.02	g/mol
Moles of Water	55.4	mol
Moles of Hydrogen	37.0	mol
Moles of Electrons	37.0	mol
Coulombs	3566060.4	C
Total Current:	0.48	A
Could Power for:	7429292.6	s
	2.83	Months



Height = 12 ft		Voltage of Hydrogen Fuel Cell			
Constants		0.8			V
0.3048	ft/m	Need:	120		V
96485	C/mol				
Approximate Resistance of Light bulb				1000	Ω
Equivalent Resistance of Room:				250	Ω

Figure 1: Calculation which shows how long one could power the lights in a classroom using the water vapor which is in that room.

Based on these calculations, if you were to take all of the water vapor from a typical classroom on an $80°F$ day, extract every electron from the hydrogen atoms and make them available to the light sources for the classroom, these lights would be able to stay on for nearly 3 months. This calculation makes quite a few assumptions, but it is definitely enough for a proof of concept to continue on researching.

To learn how to extract water from the air, research was done on the properties of air and more specifically its water vapor content; this is an area of physics known as hygrometry. The physical properties of air must be utilized in order to cause water to condense from it. Probably the most important of these properties is the dew point of air, which is simply the temperature at which moisture in the air will condense. The dew point of air depends on the temperature, current barometric pressure, and relative humidity. The dew point is actually proportional to all of these things; temperature, pressure, and relative humidity increases all result in an increase dew point. For the temperature, this intuitively this makes sense because gases (air) expand when heated up, meaning that as the temperature of the air increases, there will be more room for water to evaporate to.

3. Research Methods

After researching how to cause the water to condense, a design was constructed based off of the following criteria:

- Allow the suns rays to permeate to heat the air,
- Choose a color which would best help to collect heat,
- Air flow should be unidirectional; i.e. no air should escape from the intake holes,
- Outflowing heated air should be expelled onto a surface such that water can condense onto it.

In order to achieve all of these criteria, a design was eventually reached which actually mimics the mechanics of attic ventilation. The whole purpose of attic ventilation is to ensure that cool air comes in to remove the heated air through an opening at the top; this keeps the attic cool and also ensures that moisture is not built up in the wood framing. This may sound counter-intuitive for the design which is needed to be built; however, if in this design the ventilation is simply made horribly inefficient, the air will still circulate properly but the inside will be hot. To take care of the first and second items in the criteria, the roof will be made of Plexiglas to ensure the sun can permeate into the system and the color of the interior will be black, which absorbs light and converts it into heat. Figure 2 shows the prototype after it was fully constructed and ready to be tested.

Figure 2: Picture of the completed prototype condensate collector.

Due to the Plexiglas roof, the sun will be able to heat the inside of the box. Holes on the sides of the condensate collector will allow cool air to flow in, and that air will be heated until it escapes through the PVC pipe at the top. The air can then expel onto a surface which the water vapor can condense onto.

While this was how the system was supposed to work in theory, something slightly different happened than what was expected. Because of the fact that the Plexiglas roof did not change temperature very much and it is pretty hydrophobic, the water condensed onto the roof instead of outside of the box where it was expected. This unexpected occurrence is shown in Figure 3.

Figure 3: Shown here is condensation which has formed on the Plexiglas roof of the prototype condensate collector.

While this was a slight inconvenience, as it will make it harder to collect the condensation, it was decided to stay with the current design to see if it could be optimized in any way.

To really understand if the system is working as it should, a remote thermometer was placed inside of the condensate collector to monitor the difference between the inside and outside temperature when condensation actually forms. Many experiments were performed to test and see how to make this work optimally. These experiments range from different roof materials to different roof shapes, heating the inside manually and placing more water in the box to manually increase relative humidity. As would be expected, manually rising the relative humidity and raising the temperature inside the box significantly increased the amount of condensation collected.

As for the roofs, a sheet metal roof painted black was tested; the logic here was that, because sheet metal has a low specific heat capacity, it would quickly heat up from the sun and just as quickly release that heat to the air inside. However, once this roof was put in place, the inside temperature dropped significantly. Most likely, the air on the outside of the roof more quickly took away the heat than the air on the inside could. A saran wrap roof was also tested. The logic behind this choice was that it is very affordable, and it is also hydrophobic which more easily provokes condensation. While this roof worked better than the sheet metal, it did not compare to the Plexiglas. This is probably due to the fact that it could change temperature more easily than Plexiglas; therefore there would not be as much of a temperature difference between the air and surface. On top of that, because the saran wrap is so flimsy, it was much more difficult to make an airtight seal for the inside of the box. This would also make it much more difficult for the inside of the box to heat up because more cool air is able to enter.

A fuel cell and electrolyzer set was also purchased to use in conjunction with this condensate collector, shown in Figure 4.

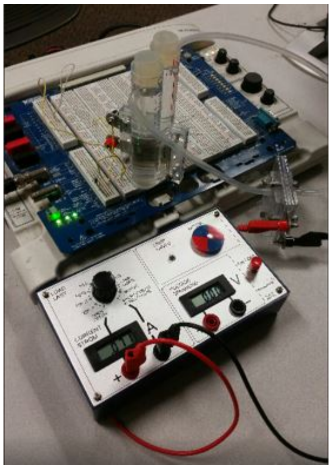


Figure 4: This is the hydrogen fuell cell, electrolyzer and multimeter which all came in a kit. This is to be used with the water that is collected from the condensate collector.

Necessary information about this fuel cell and electrolyzer include the hydrogen production rate of the electrolyzer and the power output of the fuel cell. The hydrogen production rate will tell us exactly how long it will take to consume a given amount of water, and the power output of the fuel cell will tell us how much energy output we get for an amount of water. Upon testing for these factors, it was found that the hydrogen production rate of the electrolyzer is $2\frac{mL}{hr}$ and the power output of the fuel cell is about 52mW. After an 8 hour period over night, condensation was collected from both panels of Plexiglas and weighed; 5.976g of water was collected. With this water and the above data on the electrolyzer and fuel cell, it was calculated that approximately 0.5MJ of energy would be outputted by the fuel cell; this is about the amount of energy necessary to power a 60W light bulb for 2 hours.

While this is a good rough estimate of just the amount of energy we could get from this system, there is quite a bit of uncertainty in this calculation. The method of collecting the water cause quite a bit to spill and therefore not be collected, and it is quite possible that throughout the night multiple collections could have been performed. Because of this, it is probable that more energy could have been attained during this 8 hour period than what was calculated.

4. Results and Conclusion

A prototype condensate collector was successfully built and tested under many different conditions to provoke condensation. This prototype was engineered to ensure efficient air circulation and plentiful sun exposure to the inside. As of yet, it has been determined that over an 8 hour period during the course of the night, this prototype can collect $2.8\frac{g}{ft^2}$ of water on its roof. This prototype was successful in its purpose of a proof of concept. If this condensate collector were to be commercialized, it would need to be much bigger and made out of different material. More surface area means more condensation, and more insulating materials would mean even higher temperatures and therefore more likelihood of condensation. Further studying of the prototype is necessary to come up with an optimal system for the collection of condensation. Future tests could include:

- Use of an adsorbent material to trap more water,
- Using stones or concrete as a source of heat for the night,
- Finding an easily reversible endothermic reaction to continuously cool down the acrylic panels,
- More frequent water collection to find the maximum amount of condensation this prototype can collect.

5. References

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Acknowledgments

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