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Article

Harvesting Atmospheric Water

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SUMMARY

Global water shortages and droughts have become more common and severe. One solution to address this shortage is the collection and use of atmospheric water, as it is sustainable, clean, and renewable. The objective of this project was to test various materials to determine which ones collect the most atmospheric water when exposed to the same environmental factors. The experiment observed the effect of weather conditions, a material's surface area and hydrophilicity on atmospheric water collection. The initial hypothesis was that hydrophobic materials with the greatest surface area would collect the most water. The materials were placed in the same outside location each night for twelve trials. The following day the materials were weighed to see how much water each had collected. On average, ribbed plastic collected 10.8 mL of water per trial, which was over 20% more than any other material. This result partially supported the hypothesis because although hydrophobic materials collected more water, surface area did not have a significant effect on water collection. These experiment results can be used to better understand how to maximize collection of water in drought or water insecure environments.

INTRODUCTION

Water shortages and droughts have become more prevalent around the globe. Environmentally friendly and sustainable ways of obtaining water are necessary in order to meet the increasing demands for water. Depleting water supplies brought on by persistent droughts highlight the need to identify alternative sources of water to meet demand (1). Many methods for acquiring additional water such as desalination are expensive, energy intensive and detrimental to the environment (2). Additional methods including drilling for wells deplete the existing water table and erode the quality of well water. Moreover, these methods take a significant amount of time and resources before they produce usable water (3). New and cost-effective ways to augment water collection are necessary in addition to water conservation and usage reduction.

The earth's atmosphere contains 37 million-billion gallons of water (4) (atmospheric water vapor) that can be harvested to supplement the water supply. If collected efficiently, atmospheric water can prove to be a valuable new source of water. Atmospheric water forms when liquid water evaporates and condenses into water vapor. The water vapor can return to its liquid state by condensing on a surface. Condensation occurs when a surface reaches the air temperature, causing the surrounding air to cool down (5). Since colder air can hold less water vapor, condensation occurs. Coastal areas that are experiencing severe droughts but have abundant atmospheric moisture supplied by the nearby ocean, such as California, are excellent candidates for atmospheric water harvesting (6). Areas along the coast experience marine layers of fog for most of the mornings of the year, yet these cloud formations produce relatively little rainfall. On average, approximately 5% of the air around us contains water vapor (7).

The process of extracting atmospheric water is widely available and can be accomplished by using relatively little energy particularly when compared to desalination or well water extraction. Some of the current technologies that harvest atmospheric water include dehumidifiers, cooling condensation generators, wet desiccation and large sheets of netting. Both condensation generators and dehumidifiers are machines that reduce the humidity levels of the air. A dehumidifier takes in humid air and runs the air through cooling coils. The coils lower the temperature to the dew point where the atmospheric water condenses and can be collected (8). A cooling condensation generator cools the surrounding air to the dew point instead of using coils and then collects the condensed water to be disposed of (9).

Wet desiccation collects atmospheric water by placing certain liquid solutions, such as a brine solution, in a humid environment. These liquid solutions have a hydrophilic composition which helps attract water from the atmosphere (9). Large sheets of netting are used to harvest atmospheric water. The nets are placed in foggy areas to increase the efficiency of atmospheric water collection. Not only is this material cost effective but it also has a larger surface area which can help maximize water collection (10). Natural condensation uses no energy and can also provide access to water sources. For example, a car is often covered in condensation when left outside overnight. Different components of the car will have varying degrees of condensed water depending on material (metal, glass, plastic) and degree of horizontal slope. Collecting water passively from the atmosphere in this fashion would require a method of collecting condensed water from a roof or collecting apparatus of sufficient surface area to be of use. This study conducted experiments using different materials to assess their potential for use in both passive (green) and active (energy consuming) atmospheric water recovery technologies.

The vast majority of global water use is agricultural. By facilitating atmospheric water collection for agricultural use we can greatly impact water available for other important uses. Moreover, harvesting atmospheric water lends itself to agricultural use because of the nature of farming. Most farming requires large quantities of land which could potentially host condensation collectors with larger surface areas that can extract greater amounts of water (11).

In addition to agriculture, the potential for household and industrial use of atmospheric water collection is vast. Buildings, vehicles and roads can be designed with technologies intended to maximize atmospheric water collection. In fact, atmospheric water harvesting is currently in use today by numerous companies that have developed emerging technologies designed to collect water in countries with a scarcity of clean drinking water (12). Opening our minds to the opportunities available through atmospheric water collection will provide our planet with new and sustainable sources of water.

There are many different factors that impact the amount of atmospheric water that can be collected. This experiment investigated the effects of surface area of a material, the hydrophilicity of a material, air temperature, air humidity and the wind conditions of an area. Materials and objects with larger surface areas should collect more atmospheric water because the area available for condensation is greater (13). The materials that were tested with larger surface areas were ribbed plastic and ribbed aluminum. These materials were compared to flat plastic and flat aluminum.

Temperature affects water collection from the atmosphere by influencing the amount of water that air can hold and determining the dew point (14). The dew point is the temperature at which water condenses and forms dew. A higher dew point means there will be more moisture in the air (15). For example, when the temperature is 20°C, the dew point is around 6°C at a relative humidity of 40% and 16°C at a relative humidity of 80%. The humidity of an area can also affect atmospheric water collection. Humidity measures the amount of water in the atmosphere. If there is a higher humidity, there will be more atmospheric water to collect. Climates with low humidity levels including desert climates will not contain as much atmospheric water (16). Wind conditions impact atmospheric water collection because wind can cause water to evaporate more rapidly. This can reduce extractions of atmospheric water. Windier climates may not be suited for atmospheric water collection (17).

In addition to the above factors, materials were categorized as being either hydrophobic or hydrophilic (Figure 1). A hydrophilic material is a material that absorbs and mixes well with water. A hydrophobic material is a material that repels water (18). Some examples of hydrophilic materials are milk, wood, cotton and leather. Some examples

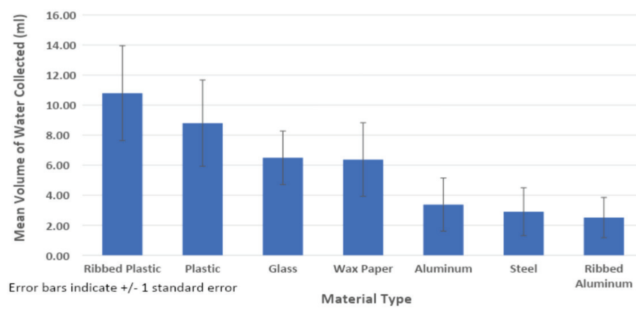

Figure 1: This chart shows the average water collected per material with error bars (+/- 1 standard error). On average, ribbed plastic collected more water than any other material (10.8 mL). This was followed by plastic (8.8 mL), glass (6.5 mL), wax paper (6.5 mL), aluminum (3.4 mL), steel (2.9 mL), and ribbed aluminum (2.5 mL).

Trial	1	2	3	4	5	6	7	8	9	10	11	12
Date	11/21	11/24	11/25	11/29	11/30	12/1	12/2	12/3	12/4	12/5	12/6	12/7
Weather Conditions												
Temperature (8pm)	11.7 °C	12.2 °C	8.9 °C	13.9 °C	12.8 °C	15.0 °C	12.2 °C	12.2 °C	12.8 °C	12.8 °C	12.2 °C	13.9 °C
Temperature (7am)	7.2 °C	7.2 °C	7.8 °C	8.9 °C	11.1 °C	13.9 °C	15.0 °C	12.2 °C	11.1 °C	11.1 °C	7.7 °C	12.2 °C
Humidity (8pm)	70%	65%	82%	55%	64%	41%	42%	64%	63%	64%	65%	55%
Humidity (7am)	83%	70%	69%	57%	68%	45%	49%	56%	57%	64%	61%	69%
Wind Speed (8pm)	5 km/hr	2 km/hr	0 km/hr	5 km/hr	5 km/hr	23 km/hr	11 km/hr	3 km/hr	3 km/hr	3 km/hr	3 km/hr	3 km/hr
Wind Speed (7am)	2 km/hr	3 km/hr	6 km/hr	3 km/hr	8 km/hr	14 km/hr	10 km/hr	0 km/hr	8 km/hr	2 km/hr	3 km/hr	3 km/hr
Dew Point	6.9°C	6.2°C	5.7°C	6.5°C	8.2°C	8.2°C	7.6°C	7.8°C	7.6°C	8.0°C	5.9°C	8.9°C
Water Collected												
Glass	2.5 mL	0 mL	6.4 mL	4.0 mL	11.9 mL	0 mL	0 mL	0 mL	13.8 mL	14.0 mL	15.2 mL	10.1 mL
Plastic	3.0 mL	0 mL	30.8 mL	2.5 mL	11.0 mL	0 mL	0 mL	0 mL	13.5 mL	20.7 mL	15.9 mL	8.2 mL
Ribbed Plastic	5.3 mL	0 mL	31.7 mL	5.7 mL	14.7 mL	0 mL	0 mL	0 mL	16.2 mL	25.4 mL	20.7 mL	9.8 mL
Aluminum	0 mL	0 mL	18.2 mL	0 mL	0 mL	0 mL	0 mL	0 mL	5.9 mL	13.1 mL	3.3 mL	0 mL
Ribbed Aluminum	0 mL	0 mL	13.3 mL	0 mL	0 mL	0 mL	0 mL	0 mL	4.0 mL	10.7 mL	2.1 mL	0 mL
Steel	0 mL	0 mL	14.9 mL	0 mL	0 mL	0 mL	0 mL	0 mL	2.0 mL	14.0 mL	3.9 mL	0 mL
Wax Paper	4.0 mL	0 mL	30.6 mL	3.0 mL	6.7 mL	0 mL	0 mL	0 mL	11.4 mL	7.5 mL	6.4 mL	6.9 mL

*Dew Point was calculated by finding the average humidity and temperature of each night and using this formula: Td = T - ((100 - RH)/5.)

Table 1: This table shows the water collected per material and the weather conditions of each trial including the humidity, the wind speed, and the temperature.

of hydrophobic materials are oil, wax, fats and fatty acids (19). The initial hypothesis was that hydrophobic materials with the greatest surface area would collect the most water.

RESULTS

Experimental materials were placed outside and measured daily for 12 nonconsecutive days. Daily results were averaged together for this time period (Figure 1). On average, ribbed plastic collected 10.8 mL of water per trial, more than any other material (Figure 1). The flat plastic collected an average of 8.8 mL, approximately 20% less than the ribbed plastic with a greater surface area (Figure 1). However, differences in water collected were not statistically significant between the ribbed and flat plastic (Student's t-test, $p < 0.05$ for all comparisons). The glass and wax paper each collected approximately 6.5 mL of water (Figure 1). Aluminum, steel and ribbed aluminum collected less than 3.5 mL of water on average per trial, less than half of what the plastic materials collected (Figure 1). In addition, aluminum collected 3.4 mL compared to 2.5 mL of water collected by ribbed aluminum, which had a higher surface area (Figure 1).

Weather had a significant impact on water collection. All of the materials collected less water on warmer days and more water on days below 10°C (Table 1). No water was collected on nights over 14°C (Table 1). This is likely because colder weather helps the materials reach the dew point. As the temperature increased, the amount of water collected by ribbed plastic (the material that collected the most atmospheric water on average) decreased (Figure 2). All of the materials collected more water on days where the humidity level was greater than 65%. Conversely, low humidity levels resulted in minimal to no water collection. For example, on December 1st and 2nd (Trials 6 and 7), the humidity level was below 50% (Table 1). On both of those days, none of the materials collected any water. As the humidity increased, the amount of water collected by ribbed plastic increased (Figure 3). Wind conditions also impacted water collection. Greater wind speeds resulted in low water collection results. As the wind speed increased, the amount of water collected by ribbed plastic decreased (Figure 4).

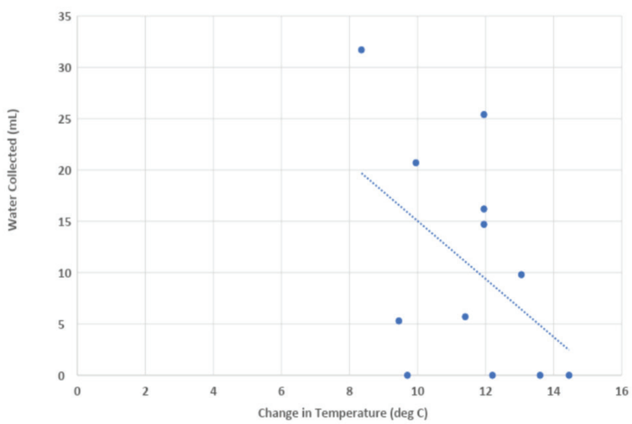

Figure 2: This graph shows the effect of the average temperature on the water collected by ribbed plastic (the material that collected the most atmospheric water on average). As the temperature increased, the amount of water collected decreased, supporting the hypothesis that a lower temperature increases atmospheric water collection.

	Surface Area	Hydrophilic/Hydrophobic
Glass	900 sq cm	Hydrophilic
Plastic	900 sq cm	Hydrophobic
Ribbed Plastic	1,200 sq cm	Hydrophobic
Aluminum	900 sq cm	Hydrophilic
Ribbed Aluminum	2,700 sq cm	Hydrophilic
Steel	900 sq cm	Hydrophilic
Wax Paper	900 sq cm	Hydrophobic

Table 2: This table displays the properties of each material, including the material's surface area and whether the material is hydrophilic or hydrophobic.

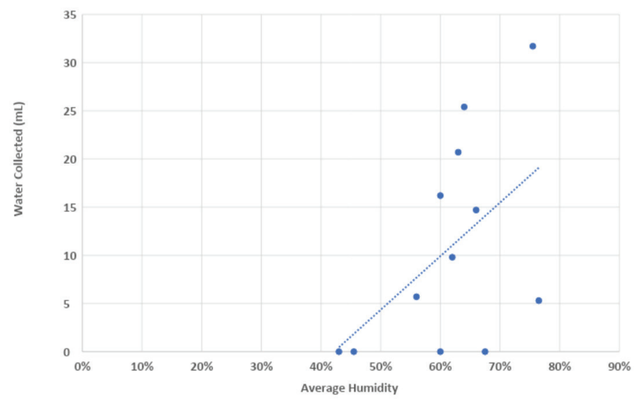

Figure 3: This graph shows the effect of the average humidity on the water collected by ribbed plastic (the material that collected the most atmospheric water on average). As the humidity increased, the amount of water collected also increased, supporting the hypothesis that a higher humidity increases atmospheric water collection.

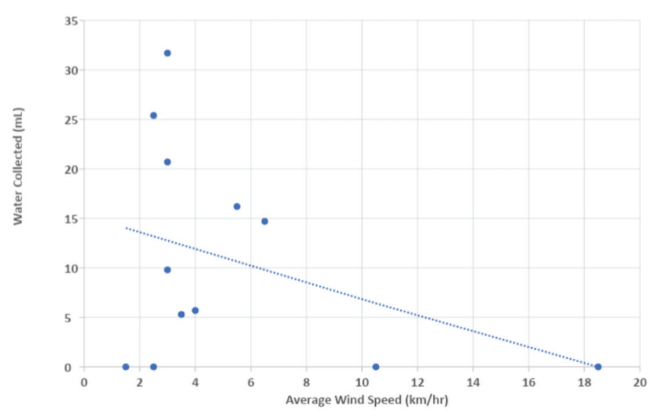

Figure 4: This graph shows the effect of the average wind speed on the water collected by ribbed plastic (the material that collected the most atmospheric water on average). As the wind speed increased, the amount of water collected decreased, supporting the hypothesis that a lower wind speed increases atmospheric water collection.

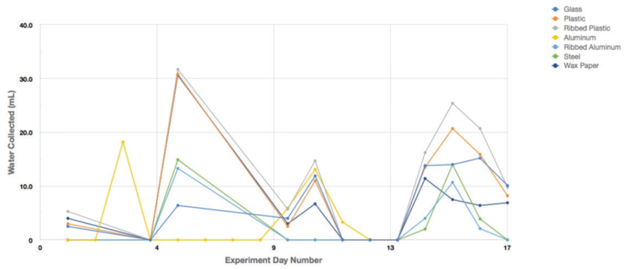

Figure 5: This graph displays the water collected per material over all 12 trials (17 days). At the highest point, ribbed plastic collected 31.7 mL of water (Trial 3, Day 5). At the lowest point, all seven materials collected 0 mL of water (Trials 6-8, Days 11-13).

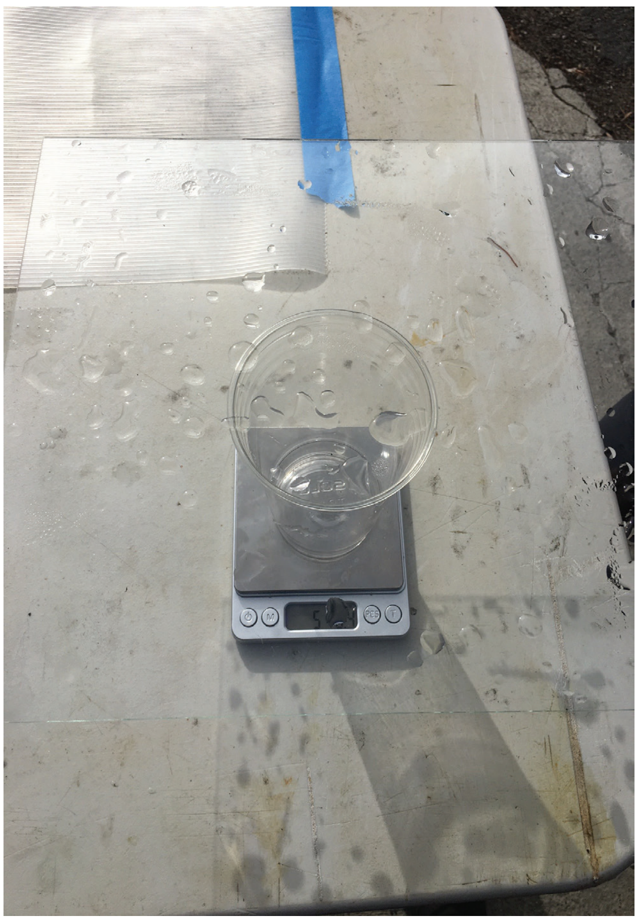

Figure 6: This is a photograph of the glass material elevated on a clear polystyrene cup to measure the material's weight.

DISCUSSION

The original hypothesis stated that if different materials such as glass, plastic, ribbed plastic, aluminum and ribbed aluminum were left outside overnight, hydrophobic materials with the greatest surface area would collect more water than hydrophilic materials. The hypothesis was only partially supported by the experimental data and observations. Although ribbed plastic (a hydrophobic material) collected the most water, other hydrophilic materials such as glass collected similar amounts of water as hydrophobic materials like wax paper. The prediction that the materials with the greatest surface areas would collect the most water was not supported by the data. The collection rates between materials with greater surface areas and their flat counterparts was not significant enough with respect to the plastic materials (Figure 5).

Water will react differently to a particular surface material depending on whether it is hydrophobic or hydrophilic. Classifying a material as hydrophobic or hydrophilic depends on the contact angle at the interface between a drop of liquid and the contacted surface. The contact angle is a quantitative means of comparing the hydrophilicity or hydrophobicity of a surface (20). If the liquid molecules are strongly attracted to the solid surface then the liquid drop will completely spread out on the solid surface, corresponding to a contact angle of 0°. In contrast if the liquid molecules are strongly repelled from a hydrophobic surface then the liquid drop will exhibit a contact angle greater than 90° (20). If the water contact angle is smaller than 90°, the solid surface is generally considered hydrophilic and if the water contact angle is larger than 90°, the solid surface is considered hydrophobic (20).

The hypothesis supported a greater collection of water with the polymers that were hydrophobic because a greater volume of water may be captured on a material with higher contact angle as the water droplets will condense into a smaller surface area. However, the trends observed in this experiment may have been affected by contamination of both the water and the surface materials used. The contact angle of a material can be significantly increased by contaminants on the solid surface or the presence of an oxide layer.

There are many other possible sources of error in this experiment. One significant source of error could have been water spilling or blowing off certain materials at night. The rate of water loss due to wind conditions may have been different for each material. In the case of ribbed aluminum, the material chosen was thinner and more susceptible to movement caused by wind. In addition, dust or debris blowing onto materials overnight may have affected the weight of the materials. These errors may have been preventable had the experiment taken place in a more controlled setting with little or no wind. Another source of error may have occurred while measuring the materials each morning. The materials had no edges and some water could have spilled off when being weighed. This could be prevented by choosing materials with edges.

The results of this experiment demonstrated the importance of considering all possible effects of weather on materials chosen to test in advance. In future experiments, sturdier materials that are more securely anchored to the surface may lead to different results. Running a parallel experiment with the same materials in a controlled weather assumed significance level for the test is alpha = .05. If the calculated P-value for a material is less than .05, the null hypothesis is rejected and the conclusion is that ribbed plastic has a higher mean water value than the alternative being tested.

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