Solar Power Integration in Water (H2O) Distillation (SPIN-HD)

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Abstract: As the world faces a looming crisis of water scarcity and contamination, water use and safe consumption have been compromised worldwide. People depend on tap water whose contamination causes a wide range of diseases, which are often life-threatening. Given that water purifying methods are not commonly accessible in households, and solar stills are only efficient with sunlight, this study employed a creation of a solar-powered water distiller prototype that can be used in small settings. The study consisted of designing and building a battery-powered safety testing setup, safety testing, designing and building of the solar-powered water distiller prototype, prototype testing, and data collection. An integration of hardware materials, i.e., 2 stainless steel cylindrical containers, AWG 14, car glow plug heater, customized condensation sloping lid, and 12V4.5Ah battery, was done in building the safety testing setup. The safety testing was followed by the removal of the 12V4.5aH battery, and the consequent integration of the 50-watt solar panel, solar charge controller, and 12V30Ah battery. After five (5) experimental testings, the solar-powered water distiller prototype produced an average volume of 58.6mL in an average heating time of 112.2 minutes, making an average distillation rate of 31.3mL/hr. Such a distillation rate was obtained under an average ambient temperature of 31.2oC, average starting battery voltage of 12.3, and average end battery voltage of 4.1.

Key Words: water distillation; solar distillation; distillation

1. INTRODUCTION

Water is crucial to human survival. It eliminates body toxins, flushes waste, and regulates body temperature. It is the key to survival that humans can only last 3-4 days without it. Unfortunately, within the past hundred years, water use has been growing at a rate more than twice the human population's growth, making water insufficient to meet global demands. As water supplies continue to shrink, some parts of the world face a looming crisis (Casella, 2019). About 4 billion people, representing nearly two-thirds of the world's population, experience severe water scarcity once a month in a year (Mekonnen and Hoekstra, 2016).

Safe and readily available water is vital for public health, primarily when used for drinking and food production. However, in 2017, 2.2 billion people do not have safely managed drinking water services located on-premises, available when needed, and free from fecal and priority chemical contamination (WHO, 2019). Consequently, people have depended on tap and underground water reservoirs for their freshwater needs but these sources do not always prove to be beneficial to one's health due to the presence of excessive salinity and deficient sanitation, which widely exposes people to water-borne illnesses, such as diarrhea, cholera, and typhoid fever.

The process of water distillation requires heat to evaporate water. The vapor, then, undergoes condensation, producing distilled water. This process removes water impurities, which can be any suspended substance, such as heavy materials, salts, and microbiological organisms (Kucera, 2005). Moreover, in distillation, solar energy can be utilized wherein the heat of the sun will heat the water, which is placed underneath a transparent cover, to evaporation. In the study conducted by Arunkumar, Vinothkumar, Ahsan, Jayaprakash, and Kumar in 2012, the most productive solar still model was the tubular solar still coupled with pyramid solar still, which has tubes and a 4-phased glass sloping top where the water vapor condensed, and accumulated. However, the downside of solar distillers like this is that although they can yield an ample amount of distilled water, they cannot function unless solar energy can be harnessed. They also depend their productivity on their size, meaning that the smaller they are, the less the volume they can subject to distillation.

As the mentioned global problem of water purifying methods not being commonly accessible in households and solar stills being inefficient in the absence of sunlight, this study aimed to integrate hardware materials to create a solar-powered water distiller, which can be used in small settings.

2. METHODOLOGY

The activities done in attaining the research objectives were composed of the designing and building of the battery-powered safety testing setup, safety testing, designing and building of the solar-powered water distiller prototype, and prototype testing and data collection. The completion of activities ranged for nine months (July 2020 to March 2021).

2.1. Materials

The materials used in building the battery-powered safety testing setup were two Phelps Dodge AWG 14 (1 meter each), stainless steel car glow plug heater, two stainless steel cylindrical containers (9in height x 8.9in diameter each), CSBattery 12V4.5Ah/20HR battery, and a customized stainless steel condensation sloping lid (See Figures 1-2).

Figure 1. Front View of the Condensation Sloping Lid

Figure 2. Bottom View of the Condensation Sloping Lid

The same wirings, heater, containers, and sloping lid were used in building the solar-powered water distiller prototype, only that a 50-watt foldable monocrystalline solar panel from Best Choice Philippines, DJ Scorpio Lead Acid 12V30Ah/20HR battery, and a PWM solar charge controller were added in the setup.

A measuring pitcher, measuring cup, Google-searched weather indicator, multimeter, and timer were used for the data collection.

2.2. Designing and Building of the Battery-powered Safety Testing Setup

In accordance with the diagram shown in Figure 3, the procedures in building the battery-powered safety testing setup involved the attachment of the car glow plug heater into the two 1-metered AWG 14, insertion of heater on the inside bottom of container 1, adjoining of reservoir container to the first container via condensation lid, and connection of AWG 14 to the 12V4.5Ah battery.

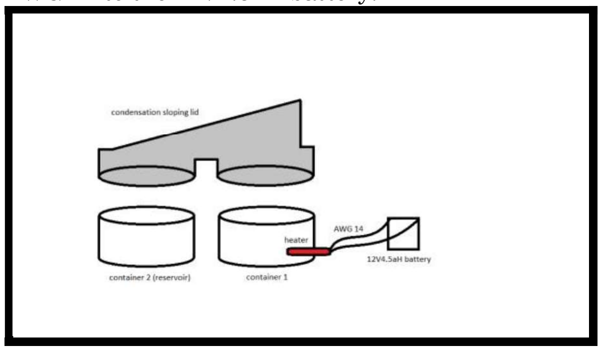

Figure 3. Battery-Powered Safety Testing Setup Diagram

2.3. Safety Testing

For this phase, 1L of water was subjected to distillation using the battery-powered safety testing setup. The safety testing determined whether the heater worked given a power source.

2.4. Designing and Building of the Solar-powered Water Distiller Prototype

The 12V4.5Ah battery was removed from the safety testing setup. It was followed by the integration of the 12V30Ah battery, 50-watt solar panel and solar charge controller, as shown in the diagram in Figure 4.

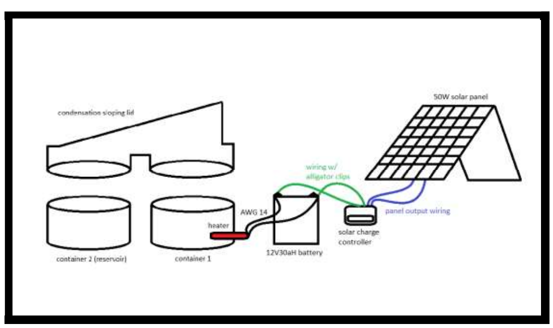

Figure 4. Final Prototype Diagram

2.5. Prototype Testing and Data Collection

The prototype was tested for five consecutive days. It was given three hours from 11AM to 2PM to perform its mechanism (Figure 5). The ambient temperature was recorded for each experiment. The solar charge controller's float charge, lead reconnect, load disconnect, programmable timer, and battery type were set as 14.5v, 11.0v, 10.7v, 24, and B1, respectively. The voltage in the battery, 5-10 seconds after the heating process started, was measured and was regarded as the starting battery voltage. The heating of the car glow plug was timed until it came to a stop. The battery's voltage was measured again and was regarded as the end battery voltage. After the system shut down, the prototype was given 40 minutes to cool down to give time for the remaining impure hot water to evaporate and condense. Finally, the volume of produced distilled water was recorded.

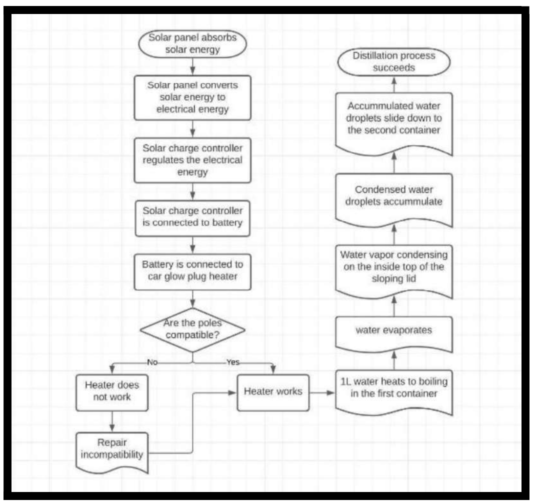

Figure 5. Prototype's Mechanism

2.6. Data Analysis

To assess whether there were significant differences in the prototype's performance, all data values from each experiment were put in a table for comparison. The mean of all data values per category was computed including the 5 distillation rates (mL/hr) that served as the prototype's average rate of distillation. The rate of distillation per experiment was determined through the formula rate of distillation= volume (mL)hour (hr).

3. RESULTS AND DISCUSSION

3.1. Safety Testing

The safety testing setup shown in Figure 6 was built according to its design (Figure 3). The incandescence of the car glow plug heater shown in Figure 7 proved that the positive and negative polar attachment between it and the AWG 14 (Figure 8) was compatible after being powered by the 12V4.5Ah battery.

Figure 6. Safety Testing Setup


Figure 7. Incandescence of Heater

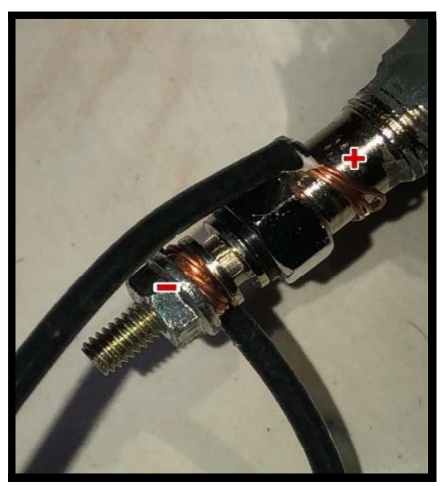
Figure 8. Heater Attached to AWG 14

As the 1L of water was heated in the first container during the safety testing, condensed water droplets formed on the cylindrical wall of the container whose surface area was not submerged (see Figure9).

Figure 9. Condensed Water Droplets on the Unsubmerged Wall of the Container

After 14 minutes, the battery was drained and the heater stopped. No distilled water was collected in the second container.

3.2. Final Prototype Testing

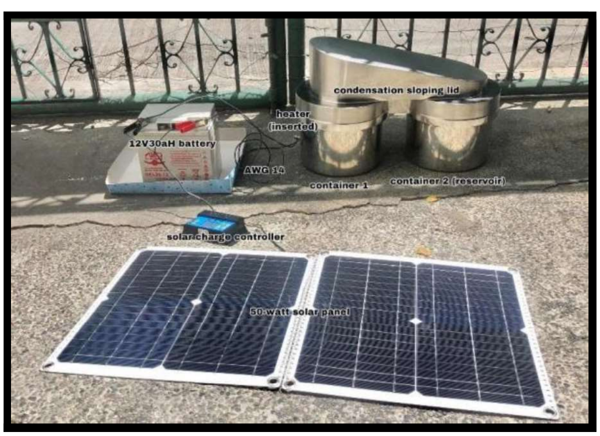

Figure 10. Final Prototype

After the safety testing, the building of the final prototype (Figure 10) was done according to its design shown in Figure 4.

Simultaneous prototype testing and data collection started when the heating process of the final prototype began. The heating process started when the wirings attached to the heater were pressed against their corresponding electrical poles in the 12V30Ah battery. The wirings' attachment and detachment to the battery poles served as the on and off of the prototype's heating process.

After the 12V30Ah battery's voltage dropped to an average of 4.1 (see Table 1), the heating process stopped. As the prototype cooled, a considerable amount of water droplets formed on the vertical bounds of the lid when it was detached from the containers (see Figure 11).

Figure 11. Condensed Water Droplets on the Lid's Vertical Bounds

The testing results after the 5-day trials can be seen in Table 1 below.

Table 1. *Final Prototype Testing Experimental Results*

Experimental trial	Ambient temperature (°C)	Starting voltage (v)	End voltage (v)	Heating time (mins)	Volume of distilled water (mL)	Rate of distillation (mL/hr)
1	32	12.4	4.1	113	59.2	31.4
2	30	12.3	4.1	109	57.6	31.7
3	31	12.5	4.1	115	59.5	31.0
4	32	12.1	4.3	108	57.4	31.9
5	31	12.1	4.1	116	59.2	30.6
Average	31.2	12.3	4.1	112.2	58.6	31.3

4. CONCLUSIONS

There was no irregularity in terms of the prototype's distillation rate obtained from each trial. The prototype was able to produce a relatively low volume of distilled water, an average of 58.6mL to be exact, in an average time of 112.2 minutes, making an average distillation rate of 31.3mL/hr. Such a rate can be obtained with specific conditions, i.e., average ambient temperature of 31.2oC, average starting battery voltage of 12.3, and average end battery voltage of 4.1.

Based on the conducted testings, it can be concluded that such a low distillation rate resulted from four main reasons. First, the containers were too big for a 1L distillation trial. A liter of water that was poured into the first container left an ample amount of area unfilled, which concomitantly resulted to the exposure of an ample amount of unsubmerged surface area in the container. The unsubmerged surface area, then, became a vertical bound where the vapor adhered, condensed, and dropped for redistillation. Second, there was also an ample amount of vertical surface area in the condensation sloping lid where the vapor condensed. From there, the condensed droplets also cycled to drop to the first container for redistillation as the heating process continued. Third, the car glow plug heater that was inserted was too short to reach the middle of the first container. It was only able to concentrate its heat on the container's side, which made most of the vapor condense on the inside vertical bounds of the prototype. Lastly, the solar panel's wattage is too low to recharge the 12V30aH battery while the battery continued to use up its power to supply the heating process.

Although a maximum of 3.7 liters can be poured into the first container, based on the final prototype testing, the prototype's power could only make the heating process work for less than 2 hours. A load bigger than 1 liter would lengthen the time for the water to heat and evaporate, thereby draining the battery with the prototype only producing less than an average of 31.3 mL per hour or none at all.

To yield more distilled water with the same average heating time the 50-watt solar panel and 12V30Ah battery could support, there are two ways that can be considered. First, it is recommended to replace the car glow plug heater with a circular DC heater that can evenly distribute the heat among the load. However, it is crucial to take note that the heater's wattage should not exceed 50; otherwise, the battery will drain in less than the average heating time of 112.2 minutes due to the replacement's higher consumption. Second, to avoid distilled water losses, as much as possible, minimize the surface area of the sloping lid's vertical bounds by coming up with a modified lid model. Also, the use of smaller containers is recommended if only a load of 1 liter or less is preferred for the prototype. On the other hand, to distill bigger loads using the prototype with the same containers and heater, it is recommended to raise the wattage of the solar panel, as well as the battery's voltage and amp-hour rating (Ah).

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