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Comparing the Voltage Output of Water in Drop and Flow Form Using a Piezoelectric Sensor and Hydroelectric Turbine

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Summary

Due to the harmful effects of broadly used energy sources, alternative energy sources have been widely studied. One area of interest is transferring kinetic water energy in nature, as in that from water flowing or falling, into electrical output. This work address the question of whether more voltage would be created by (rain) drops hitting a piezoelectric surface or by that same volume of water flowing through a hydroelectric turbine. To test this question, we built an apparatus for the piezoelectric (drops) system and purchased a small hydroelectric turbine for the flow system. We then used the two systems to measure the amount of voltage generated by drops of water and compared the data produced by each apparatus to see which system produced the greatest amount of voltage. The results showed that, despite the change in the form of the water, the average voltage produced both by the drops hitting the piezoelectric sensor and by the flow running through the turbine was virtually the same. The drops created on average slightly more voltage than the flow (whose volume was converted to the same estimated volume of each singular drop for comparison) did. These data show that directly harnessing the kinetic energy found in falling raindrops is as viable an option for an alternative energy source as are hydroelectric turbines doing the same with the kinetic energy found in flowing water.

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Introduction

In a time when alternative energy sources are being widely studied, water, in its many forms, has been used in a variety of ways to generate electricity. The classic example of this type of energy source is water spinning a turbine. By harvesting the kinetic energy of moving water, we are able to transfer electricity with minimal environmental impact. It is the transfer of water's abundant and powerful potential energy, to kinetic energy, to electricity, that makes water such a viable source for transferring electricity.

Water also has the ability to change forms, often appearing in flow form, as in a river or stream, or in drop form, as in raindrops. In an effort to harvest the kinetic energy water can have at all stages of its natural cycle, piezoelectric film, which harvests kinetic energy from impact, has been researched as a means of transferring the kinetic energy found in falling raindrops into electricity. Piezoelectricity is defined as electrical energy generated by pressure imposed on a crystal. These films are made of a material known as polyvinylidene fluoride (PVDF), which after being exposed to high temperatures and a strong electric field, have the ability to measure a wide range of frequencies and high-voltage outputs. Essentially, this means that piezoelectric materials like PVDF and various types of crystals have the ability to transfer the energy from an impact or strain, into electrical energy based on their atomic structure. Crystals tend to have a very organized atomic structure, which enables them to have a completely balanced charge. However, when they are put under pressure, their atomic structure is forced to shift slightly, forcing their charge to become unbalanced and thus creating a negatively and positively charged pole on either side of the crystal. It is this unbalancing of the crystal's charge that creates its electrical energy (1). The simple criteria that the crystals be placed under stress to generate charge means that they can capture energy already being expelled, as from the impact of cars or human footsteps, and piezoelectric materials have therefore been widely studied as a means of generating electricity.

Basahi, et al, (1998) introduced a device consisting of a piezoelectric sensor mounted to an angled plexiglass frame for the purpose of measuring the impact energy of droplets (2). This system fulfilled all of the necessary criteria: it was durable and water resistant, sensitive enough to register the impact of a single droplet, and capable of registering many droplets simultaneously and sending that data to the multimeter. We use a similar piezoelectric sensor and multimeter to read the data regarding the voltage generated by raindrops.

Hydroelectric turbines range in complexity from simple machines previously used to run mills to the more complex versions used to generate electricity in the Hoover Dam. To measure the voltage created from the provided flow, we used a modified hydroelectric turbine(3). Due to the small volume of water being used

Height[A] (cm)	Average Voltage Output (mV)
3.0	2.92
5.0	10.36
10.0[B]	1.27
50.0[B]	2.42

Table 1: Droplet height used during height determination process. [A] The height was measured from the surface of the piezo to the tip of burette. [B] At 10 cm and 50 cm the data became unreliable as the drops were not hitting the piezo surface centered, if at all.

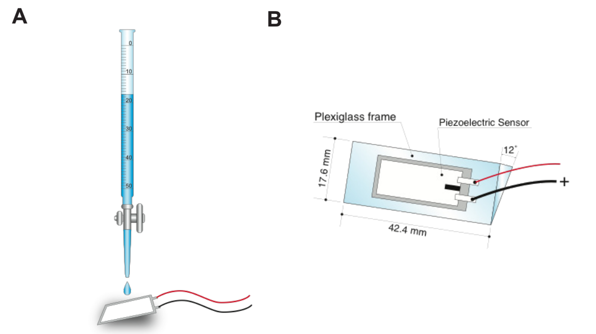

Figure 1: A) Drop apparatus centered 5 cm above the surface of the piezoelectric sensor. B) Piezoelectric sensor attached to a plexiglass frame.

for this test, the miniature scale of this turbine will work well.

We used the data collected from these two systems, to compare the voltage generated by the kinetic energy of the water in its different forms. Based on two publications related to the collection of electricity on piezoelectric devices that transfer the kinetic energy from raindrops to electrical energy, and what is known about hydroelectric turbine energy transfer respectively, we inferred that the small scale hydroelectric turbine should generate more voltage than the same volume of water hitting the piezoelectric surface from the same height and at the same rate (4) (5). We discuss here a comparison of the voltage output of the same volume of water spinning a hydroelectric turbine and the output of that volume of water hitting a piezoelectric sensor.

Results

This work aimed to answer the question of whether the kinetic energy of falling rain drops impacting a surface could be harvested to generate a voltage worthy of collecting on a large scale like the kinetic energy produced from water flowing through a turbine has been deemed.

In order to try and answer this question, we ran a trial for each form of water. To determine how much voltage could be produced from rain droplets of the same volume impacting a piezoelectric sensor, we first had to determine the optimal drop height, as measured from the surface of the piezo to the tip of the burette. It was determined through multiple trials at varying heights that the droplets should be released from a burette at 5 cm above the surface of the piezo sensor in order to generate the maximum amount of voltage per droplet (**Table 1;** apparatus shown in **Figure 1**).

Once the proper height was determined to be 5 cm, 35 trials were run. In each trial, one 0.2 ml drop was released from a burrette onto the piezoelectric sensor. The results of each individual trial are shown in the histogram in **Figure 2**.

To determine how much voltage could be produced from the same volume of water flowing through a hydroelectric turbine, we ran 15 trials. The results are shown in **Table 2** (apparatus shown in **Figure 3**).

We found that the same volume of water (0.2 ml) impacting a piezoelectric sensor and running through a hydroelectric turbine generated virtually the same amount of voltage. The piezoelectric sensor generated an arithmetic mean voltage of 2.38 µV (**Figure 2**) while the hydroelectric turbine generated an arithmetic mean voltage of 2.35 µV (**Table 2**).

Discussion

Although previous work suggests that a volume of water running through a water turbine would generate more voltage than the same volume of water impacting a piezoelectric sensor in drop form, we found that the average voltage produced by each for a 0.2 ml (one drop) volume was similar. The average amount of voltage generated for each was so similar in fact that there was only a 0.03 difference between the two methods, and so it can be said that neither method is better for harnessing water's kinetic energy based solely on the voltage output. The average voltage produced by the hydroelectric turbine was 2.35 µV, whereas the drops impacting the piezoelectric turbine averaged a voltage of 2.38 µV.

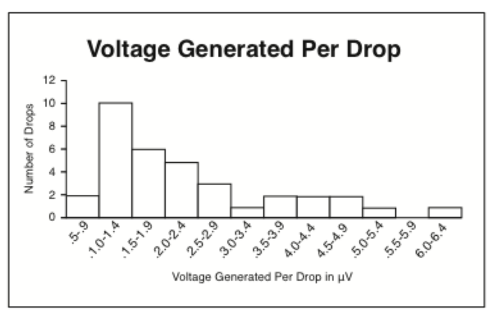

Figure 2: After respective drops were dropped onto the piezoelectric sensor, a voltage was generated and recorded. That voltage was then organized into bins to create this histogram. These data show that the majority of the drops created a voltage between 1.0 µV and 1.4 µV, although the voltage outputs ranged from 0.7 µV to 6.2 µV.

Time (s)	Volume (ml)	Volts Generated (V)	Total mV/ drop (.2 ml)
10	800	12	3.00
10	1000	19	3.80
10	1100	19	3.45
10	900	19	4.22
10	550	1.5	0.55
10	830	8.3	2.00
10	800	8.5	2.13
10	880	9.6	2.18
10	910	9.9	2.18
10	880	10.0	2.27
10	920	8.6	1.87
10	710	6.0	1.69
10	880	8.2	1.86
10	730	6.0	1.64
10	730	7.7	2.11
Average Voltage Per Drop			2.35
Standard Deviation			0.9

Table 2: Voltage generated after a differing volume of water ran through the turbine at a different rate for 10 s. and the voltage generated by each of those respective trials had the volume of water been a single drop (0.2 ml) as it was in the drop test.

The data generated from the trials showed no significant difference between the voltage outputs between the two systems. It is possible that this lack of a greater voltage being produced by the turbine over the piezoelectric film was caused by a design flaw or lack of consideration for the difference in complexity of the two separate experiments. The turbine system is notably more mechanically complex than the piezoelectric system, which involved only a sensor and an impact. The difference in electrical complexity between the two systems could account for some of the difference in voltage generated. With the turbine, much of the voltage generated could have been lost through friction before it was measured, or some of the volume of water may not have ever contributed to the spinning of the turbine and therefore the generating of voltage, which would result in a loss of voltage. The electrical and mechanical complexity of the turbine system is created by the additional resistors that could have been implemented during the trials. If the resistors were in use, they would have caused less voltage generation. It is likely this difference in complexity and therefore, efficiency, between the two systems that accounts for a large portion of the difference in voltage outputs recorded here.

Following the trials (15 trials for the turbine and 35 for the piezo), it seemed to be clear that the amount of voltage produced by the raindrops hitting the piezoelectric sensor was equal to the voltage produced by water running through the hydroelectric turbine. Though it was promising that the drop system performed in a comparable manner to the flow system, it was also troubling because it countered previous findings. This conundrum led us to reexamine the experiment in search of possible errors and to investigate what it would take to implement this system on a large scale.

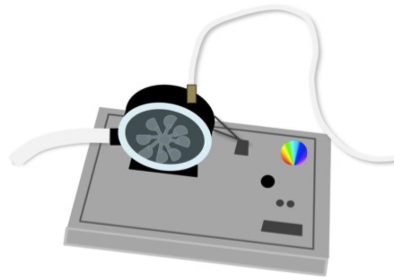

Figure 3: Hydroelectric turbine purchased from Ward Science (5).

It seems that several errors may have contributed to the results shown here. These include the lack of a consistent flow rate for the turbine trial, as we had no means of controlling flow rate. By neglecting the flow rate in each trial, the results became distorted and therefore do not honestly reflect the actual voltage output of that system. In order to prevent this error if further testing were to occur, a component might be purchased to control or measure flow rate in order to keep it consistent throughout. It was also noted that due to the lack of a consistent flow rate, the comparison between the two systems' output is also skewed as it is based on an "effective drop volume," which relies on the assumption that the kinetic energy of the water used in each system is the same, which had not been proven before testing occurred.

Another possible source of error was in neglecting to test the water drop system with differently modeled piezoelectric sensors. Based on their size and structure, different piezoelectric sensors may register impact, and generate voltage differently. By neglecting to take this fact into account, the results may not convey the furthest extent that the piezoelectric sensors can perform in terms of generating the greatest amount of voltage possible.

If this research were to continue, we would work to limit the errors mentioned previously in order to make the data comparison more controlled. As a continuation of this work, it would be interesting to investigate the other physical forms of water that have natural potential to kinetic energy, like snow flakes falling, and compare the amount of voltage they could produce from impact or some other method using only their kinetic energy.

As with all small-scale experiments, this experiment had to confront the issue of scaling. If the piezoelectric system, in particular, was ever to be implemented in real world applications as a way of producing electrical energy, it would have to be both cost effective and functional, among other necessary criteria. In order to demonstrate that this system is cost effective, we employed a theoretical model system, the football field in Gillette Stadium in Foxborough, Massachusetts. Using the standard measurements of a football field, we calculated the area of the field to be 5351.2151 m^2. Based on this information, we calculated the number of each of our systems that could fit on that surface area. We found that 138,239.9999 of the turbines, and 7,170,903.597 of the piezoelectric sensors could fit on the field. Knowing this, we calculated that, based on the information gathered from our trials and data regarding the average rainfall in Foxborough, Massachusetts over the past thirty years , the hydroelectric turbines would produce 1,305,872.063 V as compared to the 68,604,070.57 V produced by the piezos. When that is taken into account and coupled with the cost of each component (that is, one whole hydroelectric turbine as purchased and one piezoelectric sensor as purchased) we found that generating one volt would cost $1.04 using the hydroelectric turbine field, but only $0.31 using the piezoelectric field. This is, of course, not proper scaling, and much more is involved in properly doing so, but based on this simplistic attempt at scaling this system, it appears that the piezoelectric sensor system is more cost effective than the turbine system which, in and of itself, would seem to say that piezoelectric sensors are worth investigating further as a source of renewable energy.

Materials and Methods

As the goal of this work was to compare the voltage generated from water in two of its various forms, we conducted two separate experiments, each complete with their own apparatuses. The experiments, for convenience, will be separated into two sections: the Drop section and the Flow section.

Construction of Piezoelectric Sensor and Platform

The piezoelectric sensor that was ultimately used is cataloged as Piezo Vibration Sensor- Large SEN-09196 ROHS (3). In order to prevent the voltage data from being skewed by excess water remaining on the sensor after each drop, a stable, tilted platform was created and the piezoelectric sensor was attached. To construct the platform (4), we created a template on Adobe Illustrator that was scaled to the specific dimensions of the piezoelectric sensor used. Using this template, a laser cutter cut the platform out of a piece of 3mm thick acrylic. The platform consisted of one frame like shape with a rectangular hole in the center where the sensor was placed over, and two triangles meant to serve as the sides of the platform. These sides, when attached with an acrylic safe glue like Gorilla Glue, provided the necessary 12.2° tilt to the platform which allows the water to run off the sensor after each trial (**Figure 1B**).

Before attaching the piezoelectric sensor to the platform, two wires were soldered to the prongs built in to the sensor. These wires serve as the connection points for the multimeter. After attaching the wires and centering the piezoelectric sensor on the constructed platform, the sensor was attached to the platform with a standard adhesive tape. The tape attached the sensor to the platform but did not touch the actual piezoelectric element within the sensor (the gray part).

Attaching the Piezoelectric Sensor to the Multimeter

As stated above, one wire was soldered to each of the two preexisting prongs on the piezoelectric sensor. The wires were to serve as the connection between the piezoelectric sensor and the multimeter, which would read and collect the voltage data. To ensure a better connection between the sensor and the multimeter, we created a loop at the end of each of the wires. When the multimeter was attached to the wires, the probes of the meter would fit through the loops tightly, ensuring a better connection between the sensor and the multimeter and therefore ensuring more accurate data.

Construction of the Drop Apparatus

In order to create the controlled drops needed for this work, a large 50-ml burette was centered in its stand, 5 cm up, from surface to tip. (**Figure 1A**) We found that centering the burette tip 5 cm above the surface of the piezo produced the highest consistent voltage data by a single drop as compared to larger and smaller heights (**Table 1**). No fewer than five trials were run to determine the height of the drop apparatus used in the actual trials. We then filled the burette with water and dropped 35 drops (7 ml) onto the sensor, allowing time for the previous drop to roll off before the next drop was administered. When any single drop impacted the sensor, a voltage was generated and registered by the multimeter attached to the sensor in millivolts (μV) (**Figure 1A**).

Setting Up the Hydroelectric Turbine

In order to collect the voltage data produced by water running through a hydroelectric turbine, we purchased a complete small-scale hydroelectric turbine (Essential Physics Demo: Hydroelectric Turbine, Item # 160221) (5) (**Figure 3**). We then securely attached one end of a 1 cm tube to the brass fitting on top of the turbine, and the other end was fastened in the same way to the faucet aspirator. Next, we attached a wider drainage tube to a similar fixture on the side of the turbine that allowed for the water to drain out from the turbine after it had spun the waterwheel located inside the sealed turbine cavity. We placed a large bucket at the end of the drainage pipe to collect the water that had passed through the turbine.

Attaching the Multimeter to the Hydroelectric Turbine

In order to attach the multimeter to the turbine, a small, removable, LED component was taken out of two sockets in the turbine so that the multimeter probes could be placed in direct contact with the voltage being produced by the water spinning the turbine.

Collection of Data from the Hydroelectric Turbine

To collect the voltage data, we ran water through the turbine at different flow rates and collected it in a bucket. We performed this procedure so that we could measure the volume of water produced over the span of 10 seconds. By keeping the time consistent at 10 seconds per trial and collecting the volume of water that had flowed through, we determined the flow rates for each trial. While the turbine was spinning we recorded the voltage data readout from the multimeter that was attached to the turbine circuit. This method allowed us to establish the voltage output per trial. Based on the voltage data and the flow rate, we discerned how much voltage had been created per 0.2 ml "drop" in each trial. After finding the voltage created by each "drop" from the water flowing through the turbine, we could compare the voltage data between the two systems of generating electricity.

Data analysis

We calculated the following:

flow rate:

$\frac{1}{4}\pi$ (pipe diameter)^2 (velocity of the water). [Eq.1](6)

total volts/ml:

(volts generated) ⁄ (volume of water) = (volts generated)⁄(1 ml of water) [Eq.2]

volts/0.2mls drop:

(volts generated)⁄(1 ml of water) = (volts generated)⁄(.2 ml of water) [Eq. 3]

mV/drop:

(volts⁄drop)(1000) = (mV⁄drop) [Eq.4]

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