Experiment to find out the effects of the temperature of water on the current produced by a hydro-powered generator

Subject: Physics

Word Count: 3,955

Abstract

The research question of this investigation is: How does the temperature of the water (°C) (ranging from 5 to 35°C) flowing through a turbine of a hydro-powered generator, affect the current generated (Amperes) in the copper coil of the hydro-powered generator provided that the magnetic field strength of the magnets (teslas), power of pump supplying water and scale of generator remains the same?

The hypothesis aims to present the relationship between temperature of water and current produced by a hydro-powered generator, stating that as temperatures fall (controlled using a water-bath), current generated increases. The experiment is based on the principle of changing density of water, and the fact that rate of flow of water changed with temperature. The experiment was conducted by finding the angular velocity of the turbine of the hydro powered generator at different temperatures using a rotary sensor attached to the wooden rod which spun with the turbine. This gave the angular velocity in rad s^{-1}. Using this value, the actual electromotive force produced in the circuit was found. Then, using ohm's law, the current generated in a copper wire as a result of a specific amount of voltage across the coil was predicted.

The hypothesis was supported in that colder water led to a higher induced voltage. This is due to the increase in the density of water at colder temperatures, which means that the force exerted on the turbines increases, therefore leading to greater angular velocity and greater rate of change of magnetic flux meaning higher electromotive force and current.

The significance of this is to be able to better plan the positioning and locations of hydro powered generators and wind turbines. With engineers advising governments of the ideal positioning of generators, efficiency of hydro-powered generators could increase thereby reducing dependency on fossil fuels.

Word Count – 299 words

Contents

Part 1: Introduction

Research Question

How does the temperature of the water (°C) (ranging from 5 to 35°C) flowing through a turbine of a hydro-powered generator, affect the current generated (Amperes) in the copper coil of the hydro-powered generator provided that the magnetic field strength of the magnets (teslas), power of pump supplying water and scale of generator remains the same?

Rationale

Dependency on fossil fuels is one of the largest contributors to global warming. The ideal solution to this problem is to find another efficient energy source. This investigation, by finding the relation between the temperature of water flowing through a turbine and the current produced allows for increased efficiency of hydro-powered generators. By finding out the ideal water temperature, engineers can advise governments on where to build their hydro-powered generators, leading to increased efficiency of renewable energy generation. This in turn would lead to increased government dependency on hydro-power over fossil fuels.

Background Information

Currently, 17.5% of the world's energy is generated by the flow of water through a turbine. Norway is powered 99% by hydropower, Canada by 57%, Switzerland by 55%, Sweden by 40%, and USA by 7%. (Maxi Pedia)

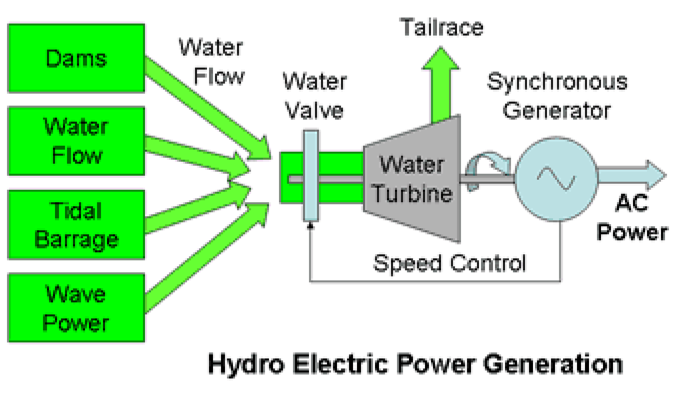


Figure 1 Simplistic model of hydro-powered generator taken from Woodbank Communications

The simplistic design of the hydro-powered generator is as shown in figure 1, where water comes through from any one of the sources shown in figure 1, passing through the turbine leading to the generation of electricity in the synchronous generator (magnetic field provided by magnet rather than current flowing through wire) and therefore, the generation of AC power.

Water turbines also depend on the fluid dynamics. (Woodbank Communication) Bernoulli's principle is a very important concept to bring in here, as this deals directly with temperature changes and fluid dynamics. It states that an increase in the speed of a fluid leads to a simultaneous decrease in the pressure applied, and this would mean that it would be a decrease in the force applied on the turbines by the flowing water. (University of Winnipeg)

The water falling from an upper reservoir has only gravitational potential energy at the top due to its height. This gravitational potential energy is then converted to the kinetic energy of the water molecules as a result of the water falling. The kinetic energy of the water is then converted to the kinetic energy of the turbine, as a result of the force exerted by the water on the turbine. This in turn leads to the transformation into electrical energy as a result of the changing magnetic flux linkage. This is attributed to Faraday's Law of Induction which states that the magnitude of the induced electromotive force is directly proportional to the magnetic flux linkage. (Electrical4u) The changing magnetic flux induces an electromotive force, hence inducing a current. (USGS Water Science School)

As shown in the model I built (Figure 2), the spoons act as the rotors on the turbine, and then outside of the structure are all the loops of copper wire, and right next to it, the magnets. This is a much simpler design of what the real generator looks like. These magnets are known as the field poles and are mounted on the perimeter of the rotor, which means when the turbines spin, the magnets spin as well.

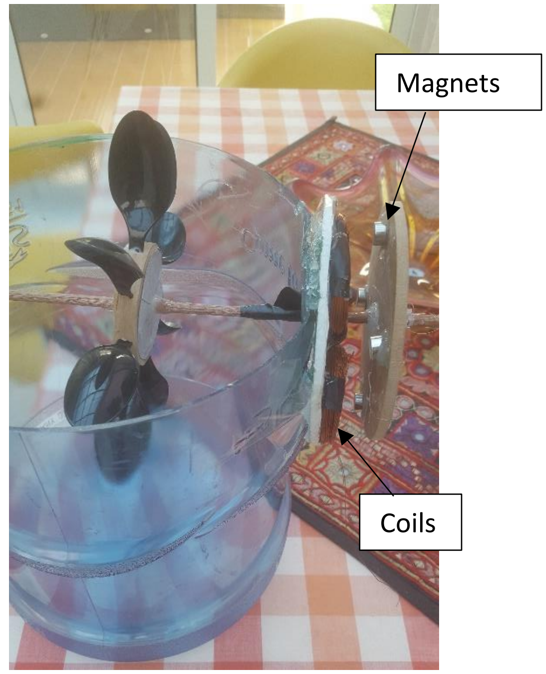


Figure 2 Image of Hydro-Powered Generator created by myself

According to published data from the London South Bank University, the density of water decreases with rising temperature. This is due to the kinetic energy of the molecules, resulting in the molecules being more spaced out from each other. As shown in figure 3, liquid water's density has the tendency to decrease as temperature increases. The main reason for this is the change in volume. Matter expands when exposed to heat, hence leading to an increase in volume while mass stays constant. (Martin Chaplin) Density by definition is $\frac{mass}{volume}$, therefore with increasing volume and constant mass, density decreases. This explains figure 3, which shows decreasing density with increasing temperature.

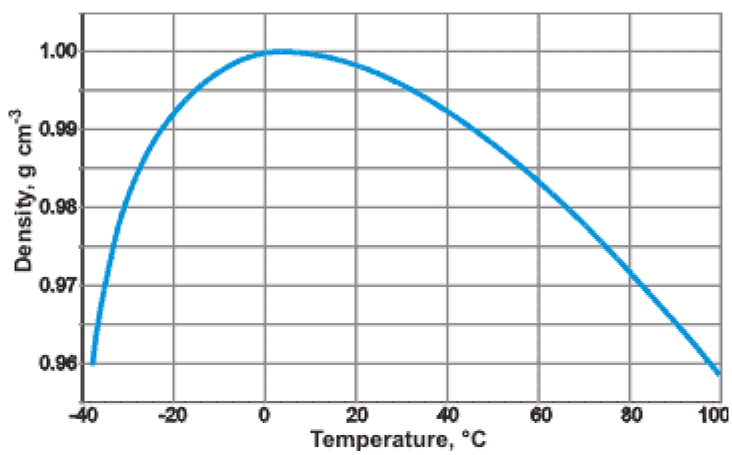


Figure 3 Graph of Temperature vs. Density by Martin Chaplin

Hypothesis

If the temperature (°C) of the water flowing over the turbine was increased from 20 to 25°C, then the current produced by the hydro-powered generator would decrease. This is because of the changing density of water as a result of the change in temperature. As said in the background information, increasing the temperature of water causes it to expand, therefore increasing the volume of the water due to the water molecules moving faster. This means the molecules aren't held together by intermolecular forces as strong as when the water is colder (forces between molecules) meaning that the density falls. The rate of flow of the mass of water should therefore fall as the particles of water are more spread out due to the falling density. This means the water should exert a smaller force on the turbines, thus decreasing the pressure, reducing the rate of rotation of the turbine.

This means that the magnets spin at a slower rate, which means the rate of magnetic flux also falls. Since Faraday's Law states that the voltage is proportional to the rate of magnetic flux linkage, voltage also falls. The current can be found using ohm's law. Resistance in the circuit remains unchanged as the temperature of the copper coil is unchanged. Thus, since V = IR, and resistance is constant, voltage is proportional to current so if voltage falls, the current generated should also fall.

There however is the contradiction that increasing temperature leads to greater kinetic energy of the water, therefore although the density of the water falls, the speed does increase. This creates the issue of the momentum of water, as the momentum is equal to the $mass \times velocity$, and while the mass falls, the velocity increases. Force as stated by Newton's second law of motion is $\frac{m\Delta v}{t}$, therefore with a decrease in mass and an increase in velocity due to increases in temperature, the force change would be minuscule. However, there would be increased energy transfer to the surroundings due to the thermal gradient. Thus, the velocity would fall back, hence the change in force would be significant due to falling mass. With falling mass, there would be a considerable fall in the force applied on the turbine, therefore decrease angular velocity of the turbine, thus decreasing rate of change of magnetic flux and a fall in the induced electromotive force.

Variables

Independent Variable	The independent variable will be the temperature of the water falling on the turbine (°C). It is controlled using the water-bath and measured using a thermometer ±0.5°C. The range is from 5 to 35°C, with the intervals being 5°C. This is the independent variable as the temperature is changed to see the effect it has on the angular velocity of the turbine, thus the rate of change of magnetic flux, hence the voltage and current. The uncertainty is ±0.5°C for the temperature due to the imprecision of the thermometer as well as the loss of heat to surroundings over time.
Dependent Variable	The raw dependent variable is angular velocity of the turbine (rad s^{-1}) which is found through the use of the rotary sensor. With this, the voltage (Volts) can be calculated through the equation $V = \frac{N(\Delta B \times A)}{\Delta t}$, where B is magnetic field strength in teslas, A is area in m^2, N is number of turns of coil and t is time in seconds. Since angular velocity is measured in rad s^{-1}, and rad is just a ratio, $N(\Delta B \times A)$ can be multiplied by angular velocity to find voltage. Lastly, ohm's law can be used to find current measured (amperes).
Control Variable	Number of spoons on the turbine – Can be controlled by using the same turbine for all trials Needs to be controlled because the number of blades on the turbine affects the torque force of the turbine. The torque force is the rotational force and with a change in the number of spoons, the moments of forces are affected which in turn can produce inaccurate and imprecise results.
	Height from which water is released - Can be controlled by not changing the height of the siphoning tube. Needs to be controlled because the height affects the gravitational potential energy of the water, which is converted to kinetic energy as the water travels. At greater heights, more gravitational potential energy exists to be converted to kinetic energy, which would increase the force exerted on the turbine.

	Material of spoon - Can be controlled by using the same turbine for all trials and independent variables. Needs to be controlled because the young's modulus of the spoon could affect the angular velocity. The young's modulus analyses the stress vs. strain of an object, essentially the pressure it can take. With a high young's modulus, the spoon is more firm, thus the angular velocity would be higher as all the water is being used to spin the turbine however with a low young's modulus meaning more fragile, the angular velocity would be less as the water would bend the spoons as well.
	Strength of Magnetic field – Can be controlled by using the same magnetic disk for all trials. Needs to be controlled because the voltage induced is directly proportional to the magnetic field strength thus a change in the strength of the magnetic field means there is a change in the voltage produced.
	Type of water – Can be controlled by using tap water for all trials. Needs to be controlled because salt water, heavy water and distilled water all have different densities, therefore, changing the force exerted on the turbine.

Part 2: Setup

Apparatus

Required materials include; 1 Circular wooden disk (Diameter 8cm x Thickness 2cm), 8 Plastic Spoons, 1 Drill, 1 Glue Gun, 1 Ruler, 1 Marker, 1 wooden rod (diameter 1.5cm), 1 plastic tub, Electrical Tape, 1 Vernier Digital Rotary Sensor to use with Logger-Pro, 1 Analog Thermometer (±0.5°C), 1 Hose, 6 magnets, 1 water bath, 1 Timer (±0.1s) and 1 Laptop with Logger-Pro.

The magnets were part of an older method, where the current was calculated through the use of an ammeter, however due to real life inefficiencies and lack of precision on the ammeter, the current was unable to be detected, therefore the method was changed to using the angular velocity and the value of the strength of the magnets acquired to calculate the induced voltage, and using the resistivity of copper, the resistance was calculated allowing for the use of Ohm's Law to calculate current. The magnets are thereby included in the apparatus as the strengths of the magnets are used in the calculations.

Method

Preparing the turbine

To prepare the turbine, first get a circular disk. It should be approximately 1.5cm thick, allowing the spoons to be stuck on it. The next step is to mark 8 equally distanced spots, for where the spoons will be stuck as shown in figure 4. Next, drill holes on the marked spots. Then, prepare the spoons: they should be short enough to fit in the hole created (cut to approximately half). Also, make sure the length of all the spoons is the same to keep the torque force constant, as it is based on moments of forces meaning the distance from the center of the turbine will affect the force. Next, stick the spoons using the glue gun, and ensure that the spoons aren't unsteady, to ensure that the spoons don't fall off when the water exerts pressure on them. The final product should look like the object in figure 4.

Figure 4 Image of the turbine I made

Next, drill a hole of diameter 1.5cm through the center of the disk, and take the tub, drilling two holes of the same diameter at the same height opposite of each other. These two holes need to be at the same height to allow the rod to spin easier as it is straight. This allows for a wooden stick to go through making the foundation for the generator as shown in figure 5. Run the rod through one end, and from inside the tub, run it through the turbine and out the other end. Glue the disk to the rod allowing the rod to spin with the disk and use the electrical tape as a nut to a bolt on either side of the plastic tub around the holes as shown by the black tape on the inside of the right side of the tub in figure 5, to ensure that the rod does not move. This reduces the loss of energy, as the movement of the rod is minimized.

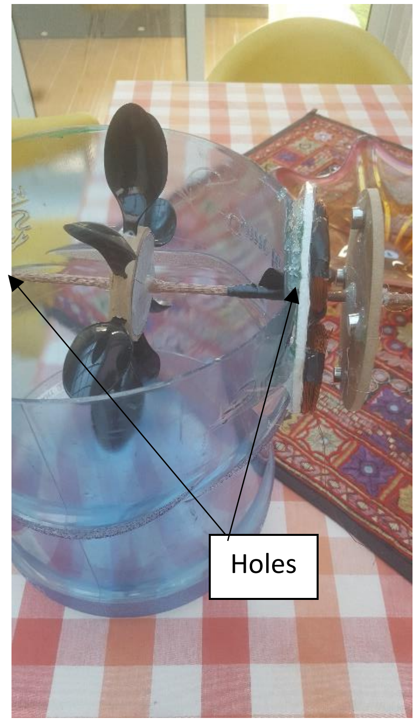


Figure 5 Final model of the generator I built

Finding rate of flow

The first step is to set the temperature of the water. Fill up the water bath and set the temperature to 5°C. Keep the thermometer in the water bath to know when it reaches the desired temperature. Next, prepare the hose: take a hose and tape one end to a beaker, taping the other end to the water bath ensuring it stays under the water. The tube needs to be siphoned (using a tube to transfer water upwards and then down to a lower level) because the water needs to go up before it comes down as shown in figure 6, so the next step is to suck on the other end of the tube to begin the siphoning process. As soon as the hose is released, start the

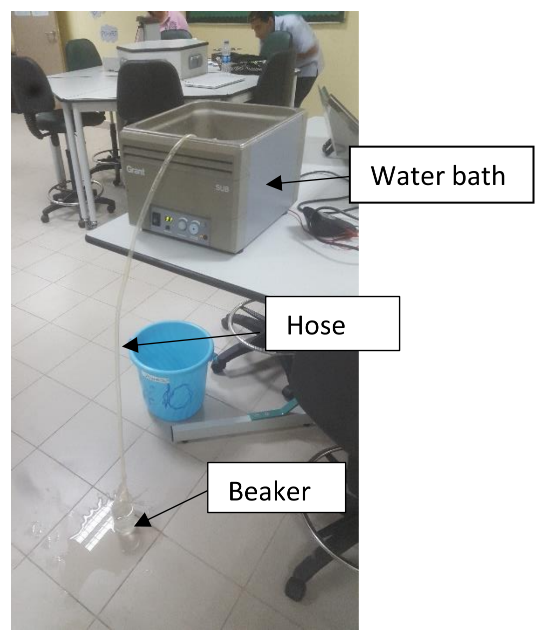


Figure 6 Experiment set up to find Rate of Flow of water

timer, and 10 seconds later, stop the process. To calculate the rate, divide the milliliters of water in the beaker by 10 solving for milliliters per second, multiply by 1.00 which is the density of water thus solving for grams per second, and then divide by 1000 for kilograms per second. Repeat the process 7 times and the whole process for temperatures 10 to 35°C.

Preparing the Experiment

First the temperature needs to be set to 5°C. Keep the thermometer in the water bath to know when it reaches the desired temperature. The next step is to set up the hose, taping one end to the table positioning it so that the hose is directly above the turbine, while taping the other to the water bath ensuring it's under the water. For the data collection, tape the rotary sensor to the wooden rod as shown in the right in figure 7, allowing us to record the angular velocity as the rod and sensor spin. Connect the sensor to the laptop and start up Logger-Pro. Begin the siphoning process and when the hose is let go off, begin the timer and data collection. Wait one minute and stop the data collection. Repeat this 7 times and then for temperatures up to 35°C, incrementing in fives.

Figure 7 Picture of final setup of experiment

The model built as shown in figure 5 looks more complicated as it is a model of the hydro powered generator. The reason for this difference is that initially, the method was to connect the generator to an ammeter and to get the current. However, the magnets were not strong enough to induce a detectable current due to inefficiencies in the real world involving higher than calculated resistance. This led to a new method which was to use the angular velocity of the turbine. In this method, the number of turns of coil, magnetic field strength, area of coil etc. are constant, based on the generator built.

Part 3: Investigation

Table 1: Raw Data

Table listing the volume of water in the beaker collected by the water flowing through the pipe at different temperatures							
Temperature of water(±0.5°C)	**Volume of water in beaker (±5ml)**						
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**Trial 7**
5.0	235	235	240	238	233	236	239
10.0	208	204	203	201	197	200	195
15.0	185	181	184	176	175	178	173
20.0	170	168	165	163	163	160	158
25.0	148	150	146	147	145	149	150
30.0	121	121	129	126	130	135	134
35.0	100	104	104	106	110	107	113

The uncertainty of the temperature is 0.5°C as it increments in 1°C. For analog instruments, the uncertainty is half the smallest increment therefore 0.5 in this case. The same can be said for the volume of water, as the increment is 10ml therefore the uncertainty is 5ml.

Table 2: Processed Data; Rate of Flow of Water

Table listing the Rate of Flow of water at different temperatures							
Temperature of water(±0.5°C)	**Rate of Flow of Water (kg/s)**						
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**Trial 7**
5.0	0.0235	0.0235	0.0240	0.0238	0.0233	0.0236	0.0239
10.0	0.0208	0.0204	0.0203	0.0201	0.0197	0.0200	0.0195
15.0	0.0185	0.0181	0.0184	0.0176	0.0175	0.0178	0.0173
20.0	0.0170	0.0168	0.0165	0.0163	0.0163	0.0160	0.0158
25.0	0.0148	0.0150	0.0146	0.0147	0.0145	0.0149	0.0150
30.0	0.0121	0.0121	0.0129	0.0126	0.0130	0.0135	0.0134
35.0	0.0100	0.0104	0.0104	0.0106	0.0110	0.0107	0.0113

Sample Equation

$Rate\ = \frac{Volume\ of\ water}{time}$ (Volume converted to grams because density is assumed to be 1g cm^{-3})

$Rate\ = \frac{Volume\ of\ water}{1000 \times time}$ (Divide by thousand to convert grams to kilograms)

$$Rate\ = \frac{235}{1000 \times 10}$$

Rate = $0.024kgs^{-1}$

The data is taken to three significant figures because the volume of water collected was to three decimal places.

Table 3: Raw Data

Table listing the angular velocity of the turbine at different temperatures of water							
Temperature of water(±0.5°C)	**Angular Velocity (±0.01rad/s)**						
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**Trial 7**
5.0	21.86	21.45	21.67	20.50	20.87	22.00	21.45
10.0	19.34	18.78	18.98	18.67	18.74	18.77	18.80
15.0	18.00	17.93	17.90	17.75	17.56	17.58	17.69
20.0	15.84	15.53	15.90	15.32	15.55	15.67	15.72
25.0	13.93	13.52	13.84	13.03	13.55	13.67	13.58
30.0	11.03	10.79	10.97	11.02	10.20	10.74	10.29
35.0	6.34	6.67	6.74	7.36	7.12	7.23	6.95

Table 4: Processed Data; Voltages

Table listing the voltage across the copper coils due to the rate of flow of water over the turbines at different temperatures							
Temperature of water(±0.5°C)	**Voltage (Volts)**						
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**Trial 7**
5.0	0.22	0.21	0.22	0.21	0.21	0.22	0.21
10.0	0.19	0.19	0.19	0.19	0.19	0.19	0.19
15.0	0.18	0.18	0.18	0.18	0.18	0.18	0.18
20.0	0.16	0.16	0.16	0.15	0.16	0.16	0.16
25.0	0.14	0.14	0.14	0.13	0.14	0.14	0.14
30.0	0.11	0.11	0.11	0.11	0.10	0.11	0.10
35.0	0.06	0.07	0.07	0.07	0.07	0.07	0.07

Sample Equation

Since the magnetic field strength of my generator was 0.01 teslas as written on the magnets, B = 0.01 teslas. Since the radius of the coil was 6cm, A = 0.01m^2 (πr^2) and N (number of turns) was equal to 100 in the generator built.

$$Voltage\ =\ N(B\times A)\times Angular\ Velocity$$

$$Voltage\ =\ 100(0.01\times 0.01)\times 21.86$$

Voltage = 0.22 volts

Table 5: Processed Data; Current

Table listing the current collected through the rate of flow of water over the turbines at different temperatures							
Temperature of water(±0.5°C)	**Current (Amperes)**						
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**Trial 7**
5.0	0.101	0.099	0.100	0.095	0.097	0.102	0.099
10.0	0.090	0.087	0.088	0.086	0.087	0.087	0.087
15.0	0.083	0.083	0.083	0.082	0.081	0.081	0.082
20.0	0.073	0.072	0.074	0.071	0.072	0.073	0.073
25.0	0.064	0.063	0.064	0.060	0.063	0.063	0.063
30.0	0.051	0.050	0.051	0.051	0.047	0.050	0.048
35.0	0.029	0.031	0.031	0.034	0.033	0.033	0.032

Uncertainties calculated and shown below.

Sample Equation

The resistivity of copper is $1.7 \times 10^{-8}\ ohm\ m^{-1}$ (HyperPhysics), the length was 100m and the radius was 0.5mm. Using the resistivity equation, $R = \frac{\rho l}{A}$, R = 2.16 ohms

$$V = \boldsymbol{I}R$$

$$0.22 = 2.16 \times \boldsymbol{I}$$

$$\boldsymbol{I} = 0.101\ amperes$$

Table 6: Processed Data; Average Current

Table listing the average current collected through the rate of flow of water over the turbines at different temperatures	
Temperature of water(±0.5°C)	**Average Current (Amperes)**
5.0	0.099
10.0	0.087
15.0	0.082
20.0	0.072
25.0	0.063
30.0	0.050
35.0	0.032

Sample Equation

$$\text{Average} = \frac{0.101+0.099+0.100+0.095+0.097+0.102+0.099}{7}$$

Average = 0.099 amperes

Table 7: Processed Data; Uncertainties

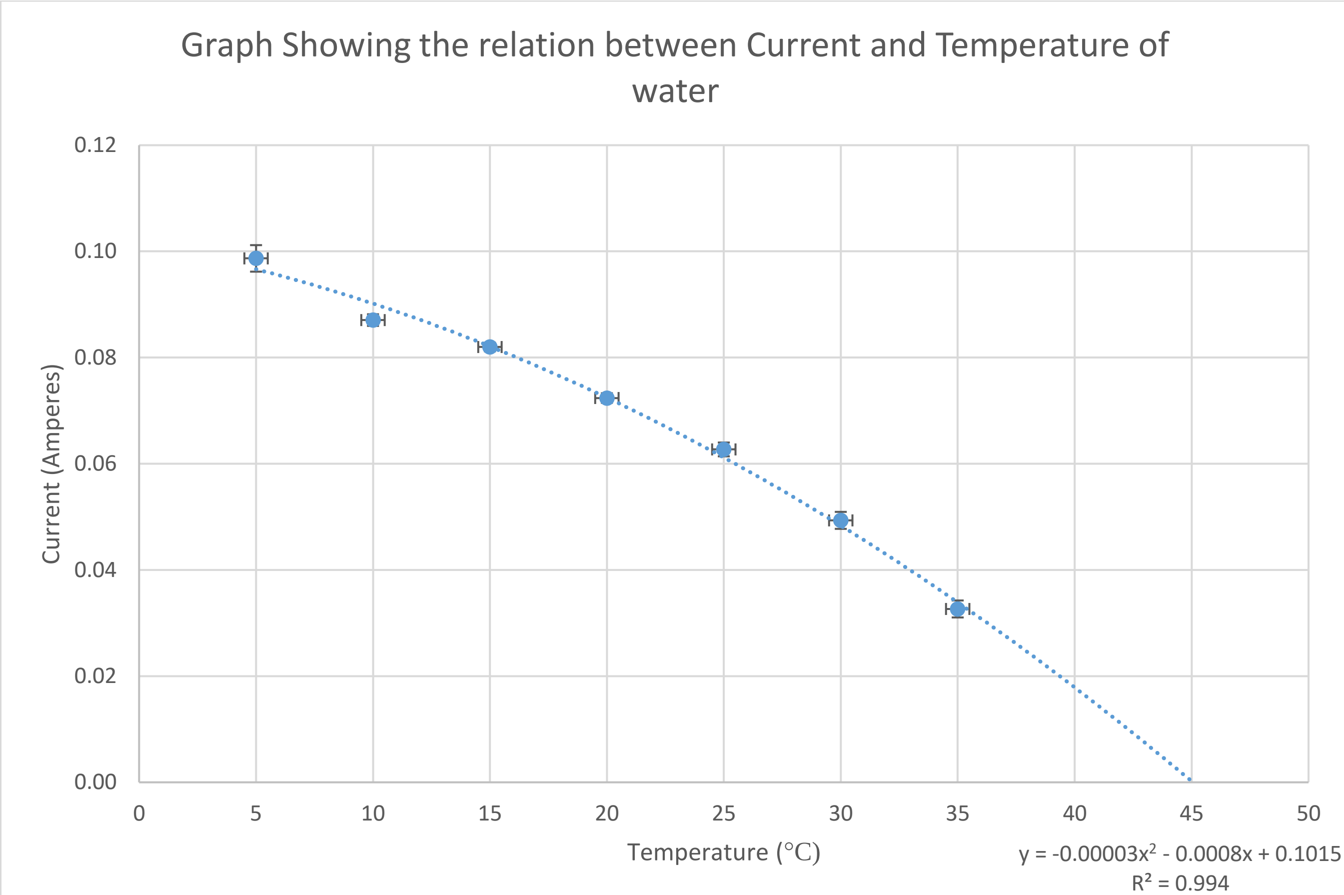
Table listing the uncertainties of the average current at different temperatures	
Average Current (Amperes)	**Uncertainty (Amperes)**
0.099	0.0025
0.087	0.0011
0.082	0.0008
0.072	0.0009
0.063	0.0013
0.050	0.0016
0.032	0.0016

Sample Equation:

$$\mathit{Standard\ Deviation\ of\ the\ values\ of\ the\ current\ produced} = \sqrt{\frac{((0.101-0.099)^2+(0.099-0.099)^2+(0.100-0.099)^2+(0.095-0.099)^2+(0.097-0.099)^2+(0.102-0.099)^2+(0.099-0.099)^2)}{7}}$$

Standard Deviation = Uncertainty = 0.0025 Amperes

Graph 1:



Some of the vertical bars are too small to be seen on the graph above.

As shown by the equation above ($y = -0.00003x^2 - 0.0156x + 2.0329$), the relationship between temperature and current induced is quadratic. This is because the relationship between temperature and density is quadratic, and density is directly proportional to the rate of flow, which is also quadratic as shown by graph 2 in the appendix. Rate of flow is proportional to the angular velocity as the rate of flow determines the rate of rotation of the turbine. Since these two are proportional, the rate of flow is also directly proportional to the voltage induced. This is because the angular velocity is multiplied by essentially a constant which is $N * B * A$. (Hyperphysics) Since voltage vs. temperature is also quadratic as shown by graph 4 in the appendix, current induced vs. temperature would be quadratic as well.

Part 4: Conclusion

Graph 1, showing the current induced compared to the temperature of the water shows that the current produced was greatest at 5°C. The graph then shows decreasing current as temperature increases past 5°C This clearly shows a negative correlation between the current generated and the temperature of the water. This occurred when all other factors such as magnetic field strength (teslas) and values such as turns of coils remain constant.

Table 2 shows that as the temperature decreases, rate of flow increases and this can also be seen in the appendix by graph 2. This is because of the fact that as temperature decreases, the density of the water increases. This happens because the particles of water at colder temperatures are more compact and together, meaning the volume of the water contracts, while the mass stays constant. With falling volume and constant mass, density increases due to the equation $\rho = \frac{mass}{volume}$ where ρ is the density. (U.S. Coast and Geodetic Survey)

Therefore, when flowing through the pipe, a greater mass of water is flowing through, and as this strikes the turbine, the force exerted on the turbine is greater as a result of Newton's second law of motion, whereby the $Force = \frac{mass \times \Delta velocity}{time}$. This is due to the fact that denser water has a greater gravitational potential energy, which is converted to a greater kinetic energy. This means that the mechanical energy of the turbine increases upon contact more at colder temperatures.

Therefore, the angular velocity of the turbine is greater, as shown by the raw data in table 3, and graph 3 in the appendix.

Since the angular velocity was measured in radians per second, and radians are a ratio, the angular velocity can be multiplied by the magnetic flux linkage, as it is being multiplied by $\frac{1}{t}$, thus giving the rate of change of the magnetic flux linkage, therefore the electromotive force. (Hyperphysics)

Since angular velocity increases as temperature falls, at lower temperatures, the rate of magnetic flux is greater meaning that voltage increases as temperature falls as shown by graph 4 in the appendix.

We know that Ohm's law states that current and voltage are directly proportional and this is supported by table 6 as well as the graph.

Although in warmer water, the molecules have more kinetic energy, the density falls therefore the mass per m^3 falls. Thus, there is an increase in the velocity of the water and a decrease in the density. This should mean that temperature shouldn't affect rate of flow, however due to the thermal gradient, the warm water loses energy to the surroundings, therefore the increase in velocity is not significant. With the decreasing density reducing mass and the velocity changing minimally, the kinetic energy of the molecules fall. This means that the kinetic energy of the turbine will be lower, therefore the electrical energy as a result of this energy being processed by the synchronous generator will be lower. This explains the contradiction between the increasing velocity and the decreasing density.

Through further research (U.S. Coast and Geodetic Survey), it was found that the proportion of increase of speed of the water is considerable less than the decrease in the mass per cm^3 of water. This therefore affirmed the hypothesis, that colder water leads to greater rate of flow, therefore greater angular velocity, electromotive force induced and current induced. This is also supported by Bernoulli's principle, which states that higher temperatures of a fluid lead to decreased pressure, and since pressure if force per unit area, the force applied falls as well. This makes sense as the torque force of the turbine would fall, thereby reducing the angular velocity, the induced voltage as well as the induced current.

Looking at the graph, the anomalous result seems to be the current for 10 degrees Celsius. It would be reasonable to conclude that all the raw data associated to this data point is anomalous as it doesn't fit through the quadratic curve. This was most likely due to random errors, as the graph fits well for the rest of the points.

The method was sufficient considering the fact that the data was quite precise. The problem however, is that the data is not accurate. This can be backed by the x-intercept of Graph 1. Ideally, water at temperatures lower than 100°C should produce some current, as they would spin the turbine. (Martin Chaplin) However, graph 1 shows the x-intercept to be at 45°C, thus showing the existence of systematic errors.

Ideally, the experiment would have been conducted between temperatures of 0°C and 5°C as well, however the water bath was unable to attain these temperatures, thus limiting the data collection from 5°C forward.

The point of this experiment was to further our knowledge of hydro-powered generators as well as wind turbines, and this has huge value in the real world. This is because this data and knowledge can be used to figure out proper positioning and locations for these turbines increasing efficiency of energy generation. Within a country, there are many temperature differences and if it can be found out where the appropriate area is to build it, governments could save money as well as reduce their dependency on energy generation from fossil fuels.

Part 5: Evaluation

Limitations	How it affects the results	Realistic improvements
Bending of spoons	The water bending the spoons is random and inconsistent, which means that sometimes, more force is being used to bend the spoons rather than spin the turbines. This was shown through the disparity in the values for each value of temperature.	Use spoons made of a different material.
Rate of flow	The pipe is not fixed and this means that the amount of water flowing through the tube is not constant. This affected the angular velocity slightly which again explained the disparity in they values for each value of temperature.	Use pipes of a different material live pvc tubing.
Splashing of Water	The water, upon landing on the turbine, would splash around due to the cupping shape of the spoons and this was evidenced by the water surrounding the generator. This reduces the impact of the water as the collision between the water and	No realistic improvement as of now due to this being a problem in real life generators as well. This is evidenced by floods caused by dams.

	the turbines causes the direction of motion of the water to reverse. Therefore, some of the kinetic energy of the water is wasted in this motion.	

Part 6: Further Study

To further enhance the purpose of this research, efficiency analysis needs to be conducted. This essay and experiment aimed to look at the geographical positioning of hydro-powered generators to improve efficiency based on climate and temperature. The significance of this is for engineers to advise governments to place generators in colder climates, to increase the efficiency of the AC current generation. However, this research could be taken a step further by looking at how much energy would be required to cool down water and how this thermal energy would compare to the electrical energy produced from the generator.

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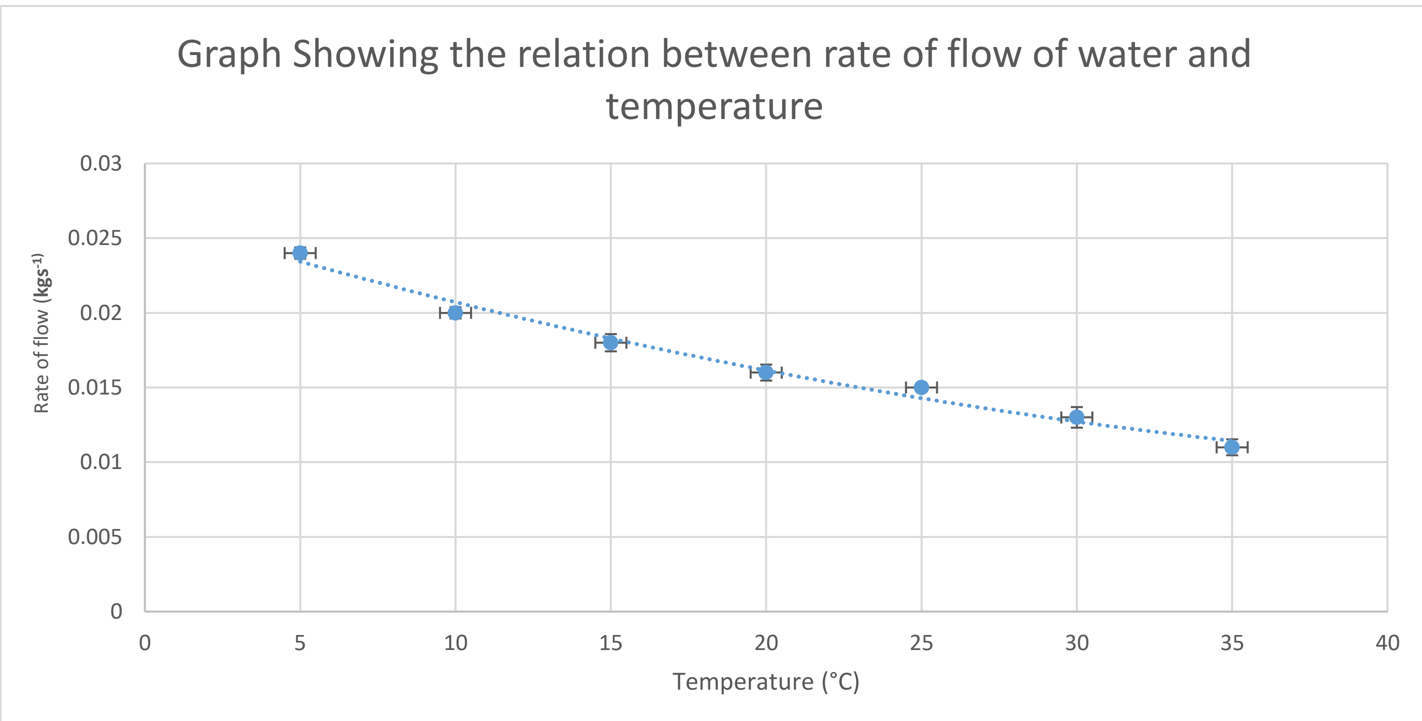
Part 7: Appendix

Table 8

Table listing the average rate of flow of water at different temperatures	
Temperature of water(±0.5°C)	**Average Rate of flow (kgs^{-1})**
5	0.024
10	0.020
15	0.018
20	0.016
25	0.015
30	0.013
35	0.011

Graph 2

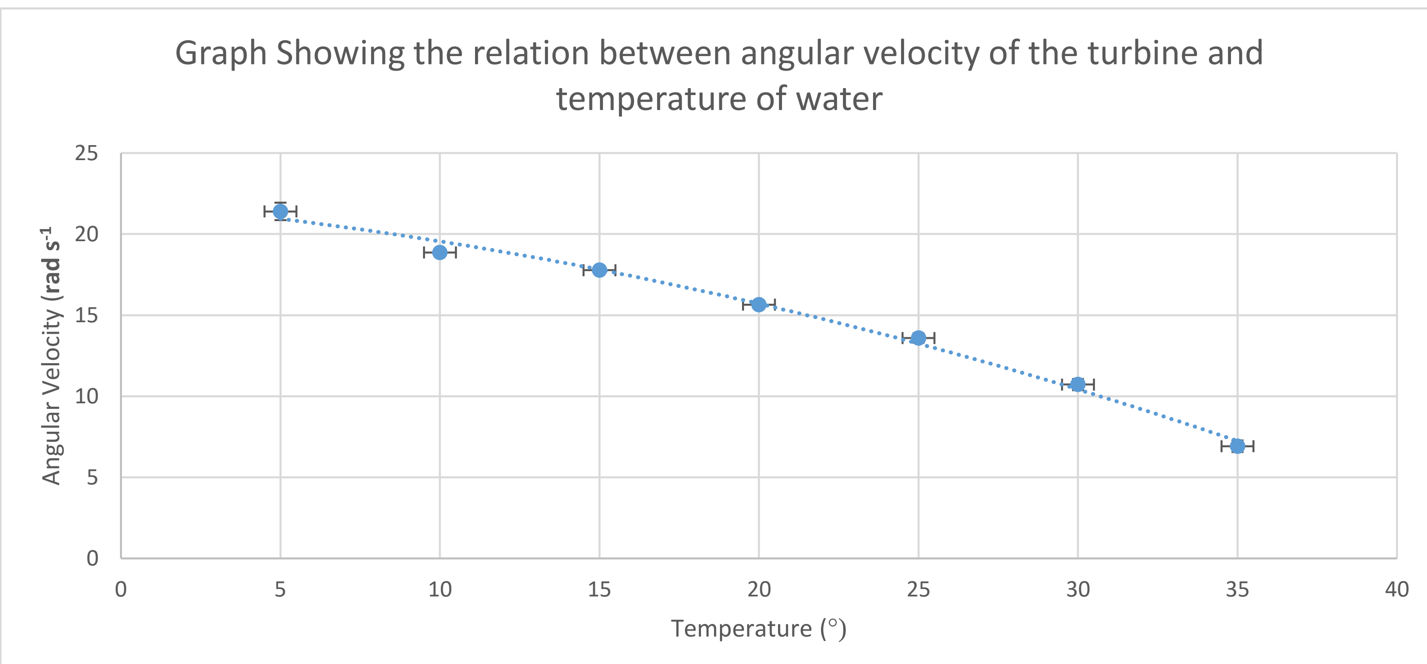


References made to the graph in the essay.

Table 9:

Table listing the average angular velocities of the turbine at different temperatures	
Temperature of water(±0.5°C)	**Average Angular Velocity (rad s^{-1})**
5	21.40
10	18.87
15	17.77
20	15.65
25	13.59
30	10.72
35	6.92

Graph 3:

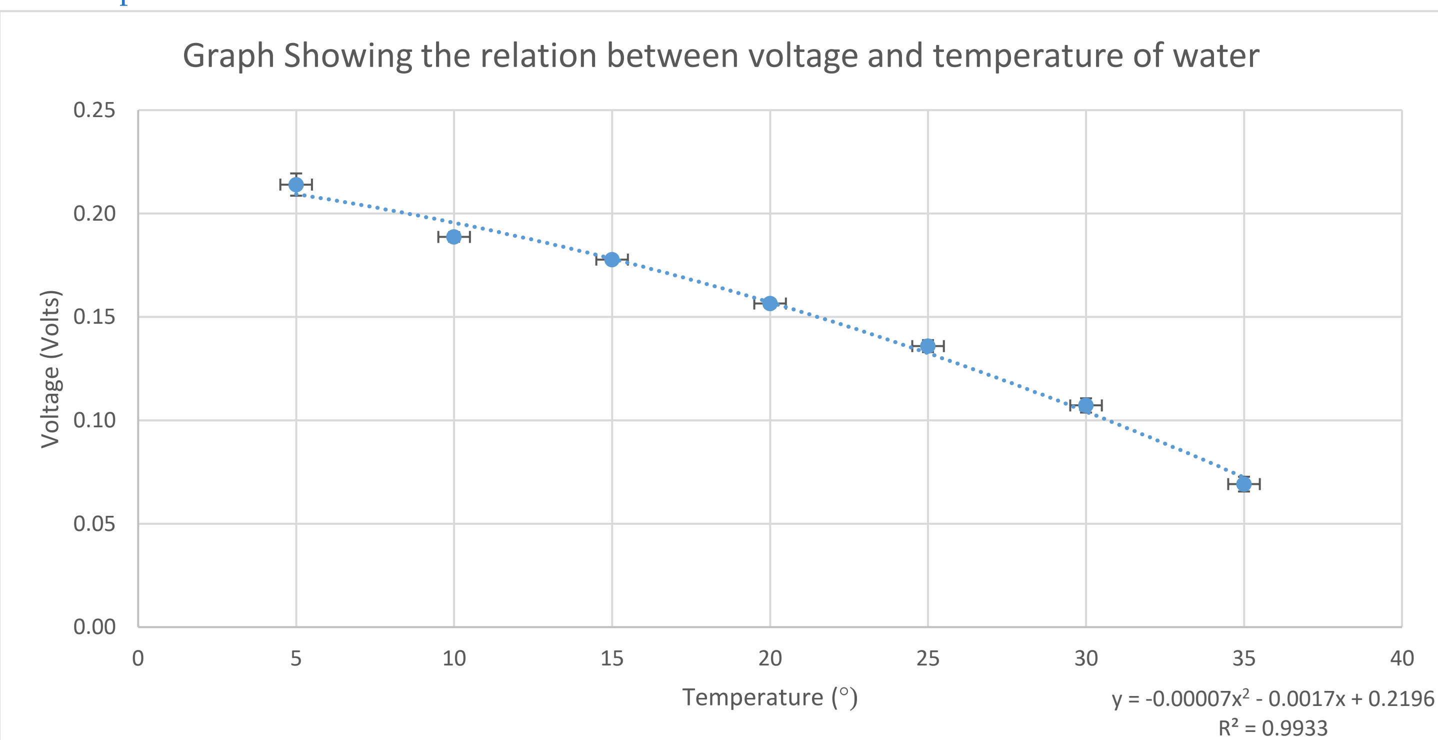


References made to the graph in the essay.

Table 10:

Table listing the average voltages at different temperatures	
Temperature of water(±0.5°C)	**Average Voltage (volts)**
5	0.21
10	0.19
15	0.18
20	0.16
25	0.14
30	0.11
35	0.07

Graph 4:



References made to the graph in the essay.