ISSN 2455-4863 (Online)

www.ijisset.org

Volume: 5 Issue: 2 | 2019

Lighting up the World with Hydropower

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Abstract: This research paper is about hydropower and was an undergraduate research project as part of the Senior Design class at California State University, Northridge (CSUN). The project developed by the research team was associated with designing a system, creating a model. running trials. and theoretically analyzing data. In the Senior Design class, a water resources module was taught by Drs. Zirakian and Boyajian in which Bernoulli's equation was presented to the students. The student research team was tasked with modeling a system that could be studied and analyzed by undergraduate students to enhance the learning process. The objective of this research was to demonstrate the fundamental relationships between flow rate, pressure, velocity, and electricity through the design, build, and analysis of a simple fluids model involving hydropower. The authors chose this model because hydropower is a renewable and environmentally friendly source of energy that has greatly benefited the world and has the potential to be expanded upon. The authors used research, teamwork, and creativity to show the relationship between water in a pressurized tank and the amount of electricity that can be produced by the flow of water.

Keywords: Flow rate, Hydropower, Pressure, Test and theory, Engineering education

1. INTRODUCTION

To help students better understand a complicated system, this hands-on project provided the necessary knowledge to further engage the concept of hydropower to students. If a student is able to see a simplified version of a complicated system, the power of imagination will inspire curiosity about how the system functions in the real world. The Senior Design class of Fall 2018 at California State University, Northridge (CSUN) was assigned a fluids-based research project with hydropower being the specific topic chosen.

Utilization of water, which is a prime element in the creation and preservation of life, has been one of the major factors in the rise of civilizations throughout the world [1]. A specific utilization of water is hydropower, which is a renewable source of energy [2]. As Christensen and Emerson state, hydropower development is a clean and efficient provider of power [3]. Hydropower contributes significantly to the

reduction of greenhouse gas (GHG) emissions and to the mitigation of global warming [4]. This research brings out one important use of water which is production of power. This paper also seeks to determine the amount of power that can be created on a small scale based on the velocity of flowing water through a turbine. Data from the experiment can be extrapolated to calculate the theoretical power that can be created from different bodies of water such as rivers, streams, creeks, and dams. When flowing water turns the blades of a turbine, the kinetic energy from the water is converted into mechanical energy. The turbine turns the generator rotor, which then converts this mechanical energy into another form of energy, electricity. The electricity hydropower can produce can be used to power homes and even cities throughout the world. Images of the earth at night show areas of prosperity, which are places where people have access to electricity, however, about 20% of the world's population remains in the dark [5]. The authors want to show the importance of creating electricity using water flowing at various flow rates from a pressurized tank.

This research paper outlines a lab project carried out to correlate the pressure and velocities of water from an orifice. The velocities of the water are measured using three different methods: direct measurement, computing through the use of Bernoulli's equation, and computing from the flow rate. The flow of water from the pressurized tank was affixed to a turbine for the generation of electrical power. The results shown in charts and graphs below indicate the variation in the velocities and voltage as pressure changed in the tank.

2. EXPERIMENTAL DETAILS

A 2-gallon pressure sprayer was used by the research team to pressurize the tank. A pressure gauge inserted into a rubber stopper served to accurately measure the pressure within the tank. A valve was used at the outlet of the tank to control water flow. A F50-12V water turbine to generate electricity. A 5V LED light bulb was used to demonstrate the use of electricity generated. Alligator clamps were used to connect the generator to the LED bulb. All pipes and fittings were 1/2" PVC. A standard voltmeter measured the voltage created by the system. A 5-gallon bucket was used to catch the outflow of water. Materials described and used in this project are shown in Fig. 1 below.

ISSN 2455-4863 (Online)

www.ijisset.org

Volume: 5 Issue: 2 | 2019



Fig -1: Tools and Materials.

In order to construct the physical model, a small drill bit was used to drill a hole through the center of a rubber stopper. An inflating needle was placed through the hole in the stopper and a pressure gauge was attached to the needle. Using a conic drill bit, a hole was drilled on the side of the tank near the bottom. A grommet was placed on a PVC converter and attached to the drilled hole using Teflon tape around the threads. The PVC pipe was then connected to the F50-12V turbine, followed by more PVC piping. A 5-gallon bucket was used to collect the water from the outlet. Alligator clamps were used to fasten the LED bulb to the turbine. The fully constructed model is shown below in Fig. 2.



Fig -2: Test Setup

3. EXPERIMENTAL AND THEORETICAL RESULTS

In the first trials of this experiment the volume of flowing water, length of the pipe, and time were used to calculate experimental velocity and flow rate respectively. To calculate theoretical velocity Bernoulli's Equation (Eq. (1)) was used. Eq. (1) uses two states of the system, state one $\binom{n}{2}$ when the system is closed and state two $\binom{n}{2}$ when the system is open. The variables used in Eq. (1) are Pressure (*P*), Height (*h*), Density of water (ρ), Velocity (*V*), and Gravitational Force (*g*). The voltmeter read the

maximum voltage created in each trial and with each increasing Pressure (P_1) in the tank, the respective Velocity (V_2) coming out of the tank increased, it resulted in a more illuminated bulb due to higher voltage outputs. This was confirmed by readings from the voltmeter during the trials of the experiment. Data is shown in charts and graphs below.

$$P_1 + 0.5\rho V_1^2 + \rho g h_1 = P_2 + 0.5\rho V_2^2 + \rho g h_2 \qquad (1)$$

Table 1 below shows all the different parameters needed for the experiment as well as all the acquired data the trials produced. At least five trials were done for each part of the experiment, each with increasing pressure. Pressure for the experiment was the independent variable.

Table 1: Data of Experiment Trials.

Trial	Pressure (psi)	Voltage(V)	Pipe Length (ft)	Time (sec)	Velocity (ft/sec)	Velocity from Flow Rate (ft/sec)	Velocity (Eq. (1))
1	0	0	9.229	1.92	4.81	5.32	6.12
2	2.5	10.8	9.229	1.38	6.69	6.99	7.01
3	5	11.15	9.229	0.88	10.49	8.79	7.78
4	7.5	11.92	9.229	0.75	12.31	12.91	8.49
5	10	12.53	9.229	0.61	15.13	14.20	9.14

As shown in Fig. 3 below, increasing pressure resulted in increasing velocity. Pressure was found by taking readings off a gauge connected to the sealed tank. Experimental velocity was found by measuring the length (ft) of the pipe from the pipe's end to the opening of the valve and then measuring the time (sec) it took for the water to exit the pipe under different pressures.

Fig. 4 below shows that an increase in pressure causes an increase in velocity. Pressure was found by taking readings off a gauge connected to the sealed tank and using Eq. (1) theoretical velocity can be calculated.





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ISSN 2455-4863 (Online)
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www.ijisset.org

Volume: 5 Issue: 2 | 2019



Fig -4: Pressure versus Velocity from Bernoulli Equation

As shown in Fig. 5 below, with pressure increasing the voltage output increased as well. Pressure was found by taking readings off a gauge connected to the sealed tank. Voltage was found by taking readings off the voltmeter connected to the turbine as the system was running.



Fig -5: Variation of Pressure vs Voltage

4. DISCUSSION

The experiment was successful in depicting a smallscale model of how hydropower works. It was able to show that higher velocities and flow rates will create more power. As pressure was increased within the tank, the respective velocity of the water exiting the tank increased as well. Pressure versus velocity data is graphed linearly to project the averages of how much impact the change in pressure caused. The lines on the graphs indicate that pressure and velocity are directly proportional. To obtain the velocities, three methods were used: Bernoulli's equation. flow rate equation. and directly from the trials of the experiment. The velocity computed from the flow rate tended to produce lower velocities compared to data from the Bernoulli's equation for low values of pressure (0 - 2.5 psi). For higher values of pressure (5 - 10 psi), the flow rate equation provided higher values of velocity than the data from Bernoulli's equation. The measured velocity was on average higher than the velocities obtained from the computation methods. The experiment also showed that with each increasing velocity, power output from the turbine increased, creating a higher voltage, resulting in a brighter light in the bulb.

The experiment was designed to simulate and aid students in understanding the inner workings of Hydropower on a smaller scale. It is observable that with the pressure building inside the tank, the flow of water coming out of the tank, and the power generated by the flow of water through the turbine, power can be created at fairly low velocities. In this experiment, a model was created to portray the different aspects of hydropower. In order to obtain different velocities from the water, a tank that could hold between 10-15 psi of pressure without any leaks needed to be developed. Once the system was constructed, the research team was able to create and control the flow of water out of the tank and into the turbine. Next, as discussed earlier, the turbine was able to convert the kinetic energy into mechanical energy which then was converted into electricity. By observing the progression of this model and looking at the results, students can expand their knowledge of hydropower and observe that it has the potential to provide clean power to people around the world.

As students of CSUN, the individuals of the research team all come from different backgrounds, religions, and cultures. Through collaborating skills and knowledge, the team can accomplish complex modern problems. CSUN aims to represent diversity and one way that is accomplished is through such collaborative endeavors. Doing this project has helped the team come together as a unit and get to know each other's strengths and weaknesses. This project has additionally helped students develop better time management skills and to grow as individuals in the professional world.

6. CONCLUSION

The experiment provides a simulation of the hydraulic conditions in hydropower generation. Using the data factoring in flow velocity, size of the fan blades, the capacity of the motor, and the rotation speed of the rotor a turbine can be created that can provide between 2 and 6 Kw when installed in a river that flows at 3.9 ft/sec, which is a much slower rate than even the velocities in the system in this experiment (up to 10-15 ft/sec). This wattage is enough to power a house and is the equivalent to between 6 and 10 solar panels. With this technology, power can be furnished to areas in need and can be easily sustained by the natural flow of water. In addition to its real-world application, it serves as a gateway to intrigue and guide students in understanding the concepts and principles behind hydropower. As harnessing renewable energy becomes more efficient, hydropower is among the greatest natural providers with very little upkeep needed after installation.

International Journal of Innovative Studies in Sciences and Engineering Technology (IJISSET)

ISSN 2455-4863 (Online)

www.ijisset.org

Volume: 5 Issue: 2 | 2019

ACKNOWLEDGEMENTS

The student research team would like to express their sincere gratitude for the help offered by Dr. Tadeh Zirakian and Dr. David Boyajian, Professors of Civil Engineering in the Department of Civil Engineering and Construction Management at California State University, Northridge.

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