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Design and Development of a Pico-hydro Pelton Turbine Bucket Using Recycled Polyethylene Terephthalate Bottles

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Abstract: The Philippines is an archipelago that consists of 7,107 islands, many of which are rural areas. Rural areas at most are off-the-grid, wherein electrical grids are not feasible. Pico-hydro turbines have many advantages compared to other types of energy utilization for their compact and robust size of equipment makes it easy in transporting the turbine and can easily be installed even to very remote areas. The main objective was to design a pico-hydro Pelton turbine bucket with the use of polyethylene terephthalate bottles aided by SolidWorks and ANSYS. The study only focused on using 500 mL PET bottles as an alternative material for Pelton turbine buckets. A 500 mL Mountain Dew PET bottle underwent a series of bucket model design and simulation with varying bucket cut angles from 15, 18, and 21 degrees. A 21-degree bucket cut angle was chosen to build a prototype, together with the fabrication of Pelton wheel assembly and turbine housing with the use of the existing setup. To compare with the standard bucket design, a 3D printed traditional Pelton wheel bucket was also designed and tested, observing the performance characteristic curves of rotational speed with torque, brake power and efficiency. The Pelton wheel with the PET bucket design achieved a maximum efficiency of 23.6%. In comparison with the standard design, a total of 15.4% difference was obtained. This study showed that a PET bucket designed Pelton turbine can be a viable replacement for renewable energy production, and with recommendations for further design improvements and advancements.

Key Words: Pelton Bucket; Pico-hydro Turbine; PET (Polyethylene Terephthalate) Bottles; ANSYS CFD Simulation; Pelton wheel

1. INTRODUCTION

A great number of Filipinos do not have the

A great number of Filipinos do not have the luxury of electricity and everything that comes with it. A possible solution to this is using pico-hydro turbines in rural areas. Pico-hydro turbines are chosen for the task because according to Protel Multi Energy (n.d.) a pico-hydro has many advantages compared to other types of energy utilization. The compact and robust size of equipment makes it easy in transporting the turbine and can easily be installed even to very remote areas. Pico-hydro turbines can also be built and installed by the villagers of the rural areas only needing the guidance of an expert.

Pico-hydro turbines are a feasible and appropriate form of generating electricity in rural areas, given the facts. But considering the state of the lives of the people in the said area, they would not be able to afford a generic pico-hydro turbine. A pico-hydro turbine costs too much because the materials used to make one are expensive. Materials such as mild steel, composites, etc., are used in the production of pico-hydro turbines. These of which are what makes it too expensive for the people in the rural areas. A pico-hydro pelton turbine would estimatedly cost 200,000 PHP - 500,000 PHP considering all costs of fabrication including the materials and the labor; while a standard pico-hydro turbine would go for 1,000,000 PHP - 5,300,000 PHP considering all the factors such as installation, assembly, materials, and labor costs.

An alternate form of a pico-hydro turbine can be made simply by using PET (Polyethylene terephthalate) bottles. The two share very distinct similarities not only in looks but also in its physical properties, making simple PET bottles a feasible option. The PET bottles underwent processes like cutting, etc. to better mimic the performance of an actual Pelton turbine, which was then simulated and obtained a reading for the traditional cut. The main cut was made in the PET bottle base as this part resembles the bucket of an actual Pelton turbine. This method will help cut the cost needed, resulting to a much affordable turbine for the people in the rural areas.

This not only will affect the cost in making a pico-hydro turbine but will also have an effect in our environment. This is because according to P. Ranada (2015) despite ranking amongst the highest trash collection rates in Southeast Asia, the Philippines is the world's 3rd biggest source of plastic leaking into the ocean. Not only would we be able to supply electricity for the supposedly off-grid population in the rural areas, but we would also be able to help minimize the plastic pollution in the Philippines with the product.

The objectives of the study were to design a pico-hydro Pelton turbine bucket with the use of PET bottles. The development of the bucket was aided by SolidWorks and simulation in ANSYS. It was also fabricated and tested to gather results. The study only focused on using PET bottles as an alternative material for Pelton turbine buckets. The chosen PET bottles underwent processes of Computational Fluid Dynamics, designing, and developing a Pelton turbine prototype to test the performance and efficiency of the bucket.

2. METHODOLOGY

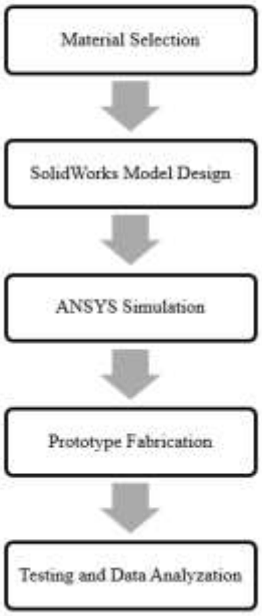

Fig. 1. Methodological Framework

Figure 1 provides a framework of the methodology that was conducted in the whole duration of the thesis process. The following methods of research and data gathering were followed to accomplish the said specific objectives of the study.

2.1 Selection of Materials

2.1.1 PET Bottles

In the selection of the PET bottle, one criterion is the shape resemblance and structure of a Pelton turbine bucket. It is essential for the selected bottle to have a thick and rigid body to be able to withstand continuous flow of water. Four (4) beverage brands were considered by the researchers – Coca Cola, Gatorade, Mountain Dew, and Pepsi – all with a volume of 500 mL. Since these are all PET bottle materials, they exhibit the same properties of plastic such as tensile strength, elastic modulus and Poisson's ratio. The selection criterion only consisted of the thickness of the bottles that were measured in three (3) different areas - bottle body, bottle base outer lobe, and the bottom part of the bottle - with the use of a micrometer. The data obtained from the measurement for initial selection are tabulated in Table 1.

Table 1. PET Bottle Thickness (in mm)

Beverage Brand	A. Bottle Body	B. Bottle Base Outer Lobe	C. Bottom of Bottle
Coca Cola	0.428	0.345	0.150
Gatorade	0.322	0.320	0.135
Mountain Dew	0.308	0.345	0.200
Pepsi	0.313	0.325	0.100

Based on the given data, the Mountain Dew bottle was chosen because it showed the best thickness results versus the other bottles. Although the thickness of Coca Cola bottle is relatively greater on other parts, the bottom part of the bottle contributes mostly to the bucket quality and resistance, because this is the area where the water jet speed will mostly be directed.

2.1.2 Pico-hydro Turbine Elements

An existing pico-hydro Pelton turbine setup done by Engr. Marfori together with his senior high school advisees was utilized and modified for the experimentation process of the study. Fig. 2. shows the assembly of the different parts of the setup. It is composed of two pumps connected in parallel, a rectangular tank housing the nozzle, runner and frame, and a pipeline linking the pump to the main tank.

Fig. 2. Existing Experimental before modification (front and back)

To measure the torque generated by the turbine, a force meter with a load cell was used with a prony brake. To measure the rotational speed of the turbine, the researchers used Arduino with a DIY infrared sensor.

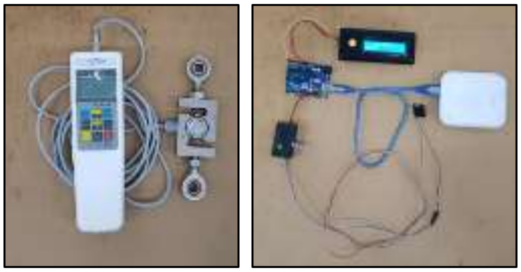

Fig. 3. (a) Force Meter with Load Cell and (b) Arduino Optical Tachometer

Due to time constraint and unavailability of machining services, the researchers decided to 3D print some of the parts used in the experiment. The traditional Pelton buckets were 3D printed from a 3D model to ensure perfect geometry and design flexibility as it matched the size of the PET Pelton buckets. The PET Pelton bucket cutouts were also attached to the runner wheel using 3D printed holders for ease of mass producing and rapid prototyping. The researchers also opted to 3D print the venturi tube instead of machining it out of aluminum due to the complexity of the design.

2.2 Bucket Model Design and Simulation

2.2.1 Traditional Bucket Model

To create a 3D model of a traditional Pelton bucket, the researchers used the technical drawing provided by Markus Elsenring in his book "Micro Pelton Turbines". The drawings were scanned and traced on SolidWorks to form sketches of the different slices available on the drawing. These slices were used to form the solid body. Modifications were added to the model so that it can be attached to the runner wheel using M4 bolt and nuts.

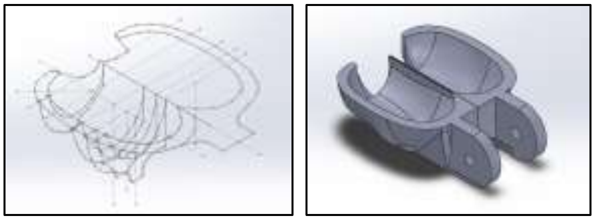

Fig. 4. (a) Slices from the Drawing Forming the Bucket's Frame and (b) Final 3D Model of the Traditional Pelton Bucket with Holders

2.2.2 PET Buckets Model

After determining the type of PET bottle to be used for the experiment, the researchers performed Silicone Molding to attain the traditional shape and geometry of the Mountain Dew bottle in preparation for SolidWorks model design. A 100% silicone sealant was used to create the mold because of its properties such as low shrinkage, permanently elastic, and low modulus. The molding was successfully achieved as seen in Fig. 5 after several trials of mixing silicone and water, drying, and cutting of the bottle.

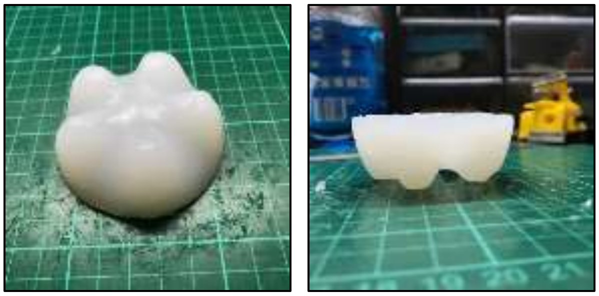

Fig. 5. Mountain Dew Silicone Mold (a) base part bottom view, (b) side view

A lobe from the mold was then sliced and photographed to obtain the curvature and geometry of the PET bottle. The photos of the slices were then imported to SolidWorks to trace the curvature and form slice sketches like the process of making the traditional Pelton bucket model.

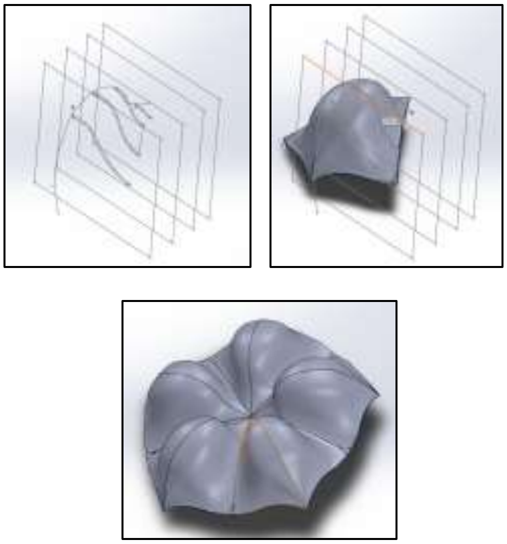

Fig. 6. Process of Modeling the PET Bottle Lobes (a) Slice Sketches, (b) Lobe Formed from Lofting the Slices, and (c) Mirrored Lobes

After obtaining the geometry of the PET bottle bottom, the bottle was then modeled and sliced to get the desired PET bucket cutout, based on the cut angle. The three models tested in CFD (Computational Fluid Dynamics) are cutouts varying by the angle of the cut, which can be seen on Figure 7.

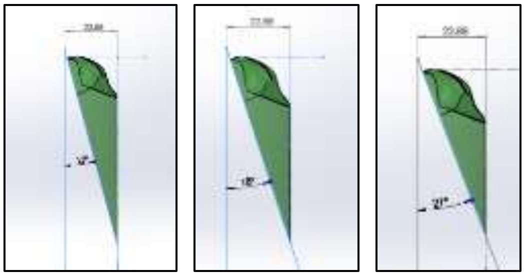

Fig. 7. PET Bottle Bucket Cutouts with 15, 18, and 21 degrees Cut Angles

Holders for the PET bucket cutouts were designed to attach them to the runner wheel, and to hold the buckets at a certain angle where the jet of water would perpendicularly hit the center ridge of the bucket. This angle was found to be 45°.

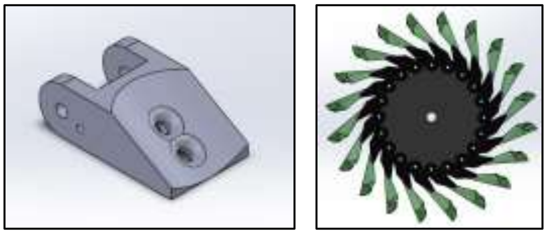

Fig. 8. (a) PET Bucket Holder and (b) Runner Assembly with PET buckets and Holders

2.3 CFD Simulation Using ANSYS

To start the simulation, a geometry file of tank with PET runner fluid domain was inserted. For the mesh section, the size was modified and named parts or selections were done. After running the Solution part with 100 iterations, the analysis proceeds to the Results section. To visually observe the flow of water jet from the nozzle, various enhancements were inserted. A 3D streamline was added to see the water velocity starting from the inlet with equally spaced sampling. An XY plane was also displayed to supplement a contour plot that showed the water volume fraction splashing at the surface of the buckets. Fig. 9 provides the resulting scenario that occurred during the setup run.

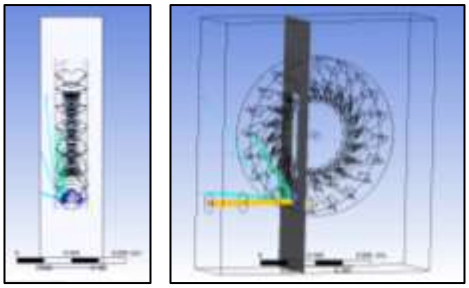

Fig. 9. Geometry result with contour, streamline, and XY plane

2.4 Pelton Wheel Assembly

Based from the calculations, a 180mm and 160mm OD (Outside Diameter) wooden runner with a thickness of 19mm was used for the traditional and PET Pelton wheel, respectively. 20 buckets were attached to both runners using a 4mm bolt and nut. The traditional buckets and PET bucket holders were 3D printed with 0.3mm layer height. The PET buckets were cut using scissors, cutters, and a rotary tool with a cutting disc. The rotary tool was needed to cut the bottom portion of the bottle because it was too thick for scissors or cutters to penetrate. The notches were also cut using the rotary tool. The PET bucket holders were attached to the wheel using nails, bolts, and nuts. The total production of PET turbine buckets and plastic waste usage depend on the sizing of the Pelton wheel and nozzle diameter. For this project, twenty PET buckets were fabricated, having a total utilization of ten Mountain Dew bottles. For further innovations, the researchers plan to study the feasibility of using other PET bottle types and turbine sizing before considering fabrication of prototypes for successful, commercial production and installation to target communities.

Fig. 10. Pelton wheel with Traditional buckets and PET buckets

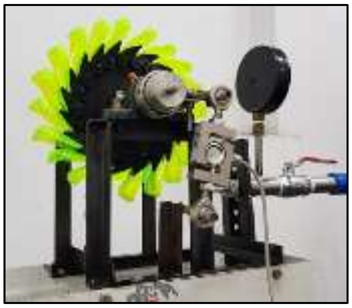

Fig. 11. Turbine Assembly with Prony Brake and Load Cell Attachment

2.4.1 Prototype Testing and Analyzation Methods

The prototype has been tested after fabrication to obtain the desired data. The researchers used a pump to simulate the flow rate and head that the turbine was supposed to work with on site. When the turbine functions properly, the necessary data such as power output, pressure head, and volumetric flow rate were determined and recorded. The researchers used the force meter with a prony brake to measure the power output, a pressure gauge for the pressure head, and a venturi tube for the volumetric flow rate. The researchers then analyzed the data and compared the results to that of a Pelton turbine with standard buckets to determine the feasibility of the turbine.

Fig. 12. Full Experimental Setup without Acrylic Enclosure

3. RESULTS AND DISCUSSION

3.1 Computational Fluid Dynamics (CFD) Simulation Results

Computational Fluid Dynamics is one essential method to study the fluid motion exhibiting in the Pelton turbine setup. This process plays a significant role in the study to determine the most effective cut shape in comparison to different intervals at the bucket angle side.

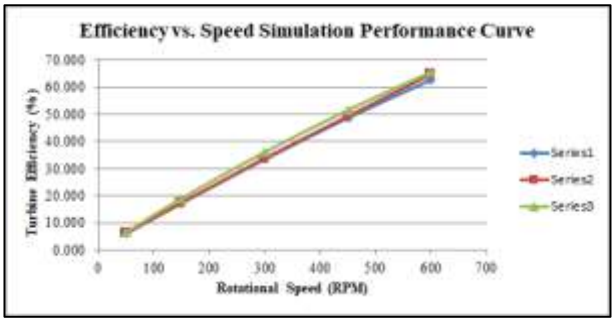

Fig. 13. Speed vs. efficiency simulation performance curve for PET buckets with (Series 1) 15 degrees, (Series 2) 18 degrees, and (Series 3) 21 degrees angle interval

As seen in Fig. 13, the rotational speed displayed a linear relationship with the turbine efficiency. The turbine becomes more efficient as the speed is being increased from the simulation. Among the three geometries, the bucket with 21 degrees angle at the side provided the highest efficiency of 65% at 600 RPM, although the values are relatively close with one another.

3.2 Actual Performance Test Results

The figures below showed the relationship between rotational speed and turbine efficiency using the traditional and PET bucket. Both figures displayed a variation in their efficiency values including the maximum point reached. The maximum point of the runner with traditional bucket is 27.57% at 344 RPM while the PET maximum point is 23.63% at 172 RPM. As the rotary speed increases so does the efficiency until it reaches its maximum point in which it will then start to decrease even as rotational speed continues to increase.

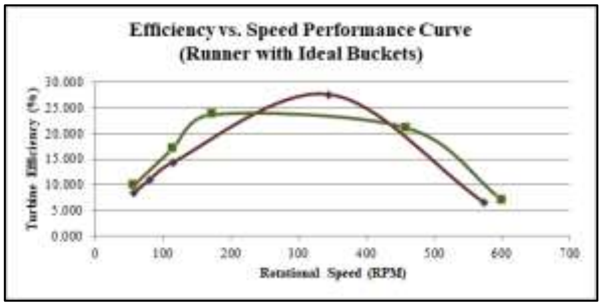

Fig. 13. Speed vs. Efficiency performance curve for the traditional Pet Bucket and the PET Bucket designs

4. CONCLUSIONS

The researchers have concluded that a Mountain Dew's bottle base would be the PET used to produce a Pelton turbine bucket. The decision was made through the measurement of parameters of four different PET based beverage brands namely, Coca Cola, Gatorade, Mountain Dew, and Pepsi. The parameters that were measured were the bottle body, bottle base outer lobe, and bottom of bottle; the bottom of the bottle being the most critical criteria among the three. Overall, the Mountain Dew bottle was selected as it has the highest overall resistance to a varying water jet speed due to its thickness.

The researchers have also concluded and decided on what cut is to be followed for the shape of the bucket to be used in the turbine. The traditional shape was formulated by allowing the silicone to mold into the shape of a Mountain Dew bottle base done multiple times to allow for variable cuts to be made for each produced Mountain Dew Silicone. Due to the silicone's effective depiction of the bottle base, a 1:1 ratio cut pattern was made based from the most accurate mold which was tested using CFD. Every cut made using the silicones was replicated in SolidWorks which was later imported to ANSYS for further tests using CFD; thus, resulting in to the current shape of the PET Pelton bucket.

Given the data from various tests and comparisons, the researchers have concluded that a PET Pelton turbine is a viable replacement and/or variation of a standard Pelton turbine. The following tests and comparisons of that being its measurements of Brake Power, Water Power, Efficiency, and its specified Performance Curves. These values are a result of the Pelton turbine and the PET Pelton turbine sharing constants and sharing a similar set up to properly identify the validity and the reliability of a PET Pelton turbine. Results show that the PET Pelton turbine can keep up, and sometimes even out perform a traditional Pelton turbine especially in the case of its efficiency as the PET Pelton turbine performed better than its counterpart albeit minimal. With the fact that the PET Pelton turbine is on par with the traditional Pelton turbine in multiple departments, suffice it to say that it can be used as an alternative for the standard ones.

5. ACKNOWLEDGMENTS

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