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Ram vs. Cycle Pump: Designing a Sustainable Water Pump for Use in the Berekuso Township

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Abstract - The world's poor rural population (900 million people) lacks access to safe drinking water and sanitation, resulting in enormous human health and economic costs, as well as gender and other societal disparities. Rural water and sanitation assistance is more difficult to provide due to the settlements' location, which is mostly in environmentally sensitive areas: dispersed settlements, an agrarian economy, and complicated infrastructure. Rural populations lack access to appropriate, low-cost, and locally manufactured technologies for water, sanitation, and hygiene. Modern, urban-oriented technologies will not be suitable in a rural setting. Other factors in technology should be considered, such as energy efficiency and the use of dependable and low-cost water transportation systems. In this project, a sustainable water pump is designed and implemented for a local town [Berekuso], in Ghana. Two distinct pump designs are proposed and compared, the ram and bike pump. The ultimate goal of this design project is to scale up the prototype for easy water transportation in a town. The product should be portable and easy to assemble – these will be tested using software simulations [Fusion 360 and SolidWorks] as well as reading physical measurements, using instruments.

Keywords - *Water, Transportation, Pump, Fusion 360, SolidWorks, ThingSpeak.*

1. Introduction

Most villages are situated close to water bodies. However, a huge amount of time is used to transport water to their homes for domestic uses, such as cooking and bathing [1]. Water is fetched with a pail and carried in a bucket to its required destination. A few farmers invest in diesel water pumps, but it is costly and can be stolen. The aim of the research is to find a solution to this timeless problem that has plagued the Berekuso community. The research team aims to develop a portable pump that can move large volumes of water at low pressure, and through a height of at least 5m, when powered. This invention hopes to bring water to the doorstep of the people. This would overall improve their productivity as the time spent fetching water can be used for other activities. With this invention, irrigation-farming can become a norm, thus increasing the crop yield every year. The designed pump must be relatively cheap, portable, and durable. The ideal pump should be able to be powered without the use of electricity. Hence man-powered/ gravity-controlled pumps are acceptable. This is particularly important as parts of a local town (such as Berekuso) lack access to electricity.

2. Research Objectives

This project seeks to develop a water pump that can be operated by the Berekuso denizens. Thus, the project should achieve the following objectives:

- Produce a pump capable of moving water through a height of at least 5 meters (2m for prototyping)
- Produce a pump that can move large volumes of water to support a village
- Produce a cheap and durable water pump
- Produce a pump that can be powered without the use of electricity
- Produce a pump that is easy to operate and maintain

To achieve the objectives stated above, other related works were considered. The research on existing water pumps will help the team ideate viable solutions. The list of requirements for the water pump will also serve as a selection criterion for its potential design. The model of the pumps will be generated in CAD (Computer-Aided Design) software, and analyzed to determine areas of interest in the design. The prototype of the pump will be manufactured, and further testing will be done to ensure its safe, and effective operation.

3. Literature Review

The motorcycle-driven water pump is mostly used in the rural community. It is set up where piped tap water is not readily available. In some set-ups, the water pump is used for small-scale (100-1000 $\mathbf{m^2}$). As per the research study that was done by [2], the water pump had a higher efficiency compared to the two other treadle pumps that were on the test. The cheap water pump gives ample output to people who cannot afford solar and gas pumps. Simple and cheap methods have been used to install stationary treadles and bicycle-pumps. For example, *Maya Pedal* makes water pumps from discarded bicycle frames. *International Development Enterprises (IDE)* also installs inexpensive power pumps that are made from bamboo. Although these water pump technologies use inexpensive, they are not portable and require custom construction. [2].

The ram pump technology was invented in the 17th century. It is based on developing a pressure surge when fluid in motion is forced to stop (or change direction) suddenly. The pressure built is then used to lift water to a point higher (supply head) than where the water originally started (deliver head). The main source of energy to hydraulic ram pump technology is the water and gravity [3]. It has low maintenance cost; it works if water is available, and the components are simple with few moving parts which can be produced locally and be maintained by the locals from the community.

3.1. User-focused Technology

One of the most important concepts of appropriate technology (and engineering in general) is the inclusion of users into a project's implementation. These are the people that the device is designed for, so one cannot afford to have a disconnect between the product, and them. As such, these individuals were sought out (these were locals and technicians that live in Berekuso). This is a summary of the insights and points from proposed users.

User 1:

- "Definitely this bike pump would be **great for agricultural** purposes, to pump water to fields."
- "But remember if it's a **motor**cycle pump, it will still need lots of **fuel."**
- "But the idea of a ram pump is interesting. Surely the **bike pump** will require people to be **constantly riding.** The **ram pump can work autonomously**. I have heard it **wastes water**, but I don't think so. Because it pumps it into the ground. So, it can be re-used later" [4].

User 2:

- "Oh, yes and it's a great idea, most people where I live have to walk **miles** to fetch water from a **stream.**"
- "For the bike pump, I like it. But then is there a way to make it such that it **spins by itself**? because maybe I will be **tired** after some time."
- "**Children** in the village **would** still **love to ride it**…all the while they will be pumping water for us all."

3.2. The Choice of Water Pump

1) *Cycle Water Pump:*

Description: When in transport mode, the frame and pump flip up and rest above the back wheel, so the bicycle can be pedaled. When it is time to pump, the bicycle stops and the frame flips down underneath the back wheel, with the **bike's tire resting against the armature of the pump.** Much like a stationary resistance trainer, the rider then pedals in place, **thus spinning the armature and powering the pump** (as seen in Figure 1). Table 1 displays the pros and cons of a ram pump.

Table.1 – Cycle water pump: Pros and Cons

Advantages	**Disadvantages**
Can potentially be interfaced with renewable energy **(solar or wind)**	Parts are more difficult to source and repair (if damaged)
Theoretically the bicycle pump has the ability to increase output revs/min by 10, as humans can ride at 100 revs/ min (max), an E-bike with a 775 motor could run > 1000rpm (accounting for friction)	For the conventional motorcycle water pump, the fuel must still be bought for pumping water. For the bike pump, the riding of a bike to pump water may get tiresome
Most people in Berekuso have access to bicycles	Important parts may be subjected to theft
Easy to understand (most locals would find the concept comprehendible – an important aspect to assure local compatibility)	–
Making your own water turbine can significantly reduce cost	–

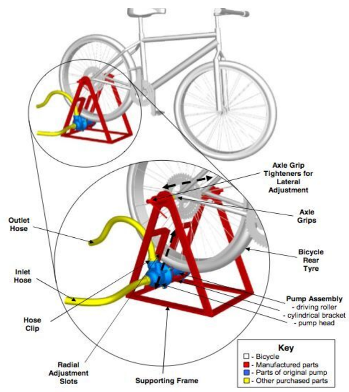

Fig.1 – Schematic of bike pump mechanism

2) Water Ram Pump:

Description: Water is pumped from a particular head at a high flow rate and comes out with a higher head but at a lesser flow rate because of the water hammer effect. The system consists of a drive pipe, waste valve, discharge valve, air (pressure) chamber, and delivery pipe. 1. (Figure 2). The only moving parts of the system are the waste valve and the discharge valve which operate from the fluid dynamic actions of the pumping cycle. Table 2 weighs the pros and cons of this ram pump.

Table.2 – Water ram pump: Pros and Cons

Advantages	**Disadvantages**
No moving parts	The water pressure from the source is discontinuous
Cheap (parts can be sourced and replaced easily)	It returns a significant amount of water to the ground through the waste valve. Since water entering the ram is pumped uphill
No electrical energy required	Loss of energy within the pump body – owing to mixing of water from different directions – is a possibility
Very easy to transport	The sudden in-flow of water could potentially wet users
Better for pumping water *vertically*	Does not have the option to be a submersible water pump

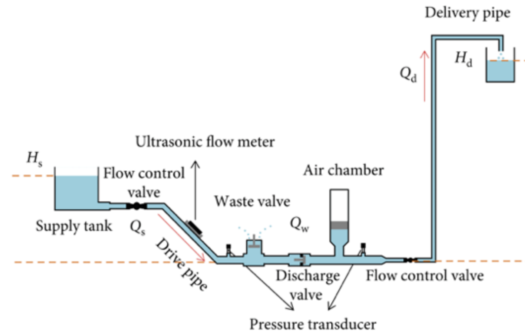

Fig.2 – Schematic of ram pump mechanism

4. Design Requirements

The choice of the different diameter pipes and components to acquire, was informed by both the type of pump, and the specific calculation.

4.1. Cycle Water Pump

Calculations and Initial Analysis:

Assuming the design of a motorcycle water pump. A motorcycle had to be simulated using a motor, this required the purchasing of a large torque motor with low noise. The price range also had to be low (**<50ghs**). For this scaled down prototype, we calculated for an rpm within an attainable pump output power. Upon further research the identified nominal commercial pump diameters and their corresponding revs per min and water head, were discovered. The nominal small pumps had a **diameter of 4 inches**, and a head of around **4m**. They however had motor rpms of **200rpm.** A shaft was also required for the bike pump. Hence, the team reversed engineered a standing fan to procure it cheaply.

Using ratio and proportion:
4m head: 200rpm
For 15m head:

New rpm = 15m x 200rpm / 4m = 750rpm.

An overestimated value was used for the motor rpm: 1000rpm **(this would account for any frictional losses that heat and sound energy will subtract from the contact of the bike tires and the motor).** The **775-motor** selected was rated at 1000rpm to about 2000rpm for 12V batteries. It cost **45ghs** (See Table 3).

Table.3 – Items bought and their respective prices (cycle pump)

Items needed	Bought or Re-used?
30W Panel	Re-used (200ghs price)
12V, 7Ah battery	70ghs
Charge controller	Re-used
775 motors	45ghs
4" Check valve (x2)	80ghs

Total cost: 195ghs + (200ghs) = 395ghs
Budget: 1,000ghs

4.2. Water Ram Pump

As previously mentioned, this ultra-low-cost water pump is the second alternative design. It was decided that the team would build and compare both pumps.

Calculations and Initial Analysis:

The pump utilizes energy from a supply head, H_s with a large quantity of water, Q_s to a delivery head, H_d which is higher than the supply head with a small quantity of water, and Q_d by rapid closure of the waste valve. The operation is continuous with no other external input and the flow is intermittent [6] – See Figure 2.
The power used to drive the pump is:

$$\text{Pow}_s = \rho g Q_s H_s. \quad (1)$$

The power added to the fluid is:

$$\text{Pow}_d = \rho g Q_d H_d. \quad (2)$$

The efficiency of the pump is defined as:

$$Q^* = \text{flow rate ratio} = \frac{Q_d}{Q_s} \approx 1 - \frac{Q_w}{Q_s}. \quad (3)$$

where H* = head ratio = Hd/ Hs and

$$\eta = \frac{\text{Pow}_d}{\text{Pow}_s} = \frac{\rho g Q_d H_d}{\rho g Q_s H_s} = \frac{Q_d}{Q_s} \cdot \frac{H_d}{H_s} = Q^* H^*, \quad (4)$$

From the research conducted by Jurata et. al. [6], they used a 1-inch diameter for their pipes and check valves – which corresponded with the above equations. To utilize these equations, all pipes and check valves were chosen to be 1 inch as well. This was intended to achieve an efficiency > 90% and a delivery head, H_d > 1.8m.

- The supply head, H_s (distance from the testing water tap to the ram pump) = 150cm (fixed)
- With a volume (quantity of water, Q_s to a delivery head) = 20L
- The quantity of water that ought to be delivered should be 80% of the supplied water (accounting for water loss). Therefore Q_s = 80/100 * 16L = 20L

-Using equation 1: Pows = 1.244 x 9.81 x 20 x 1.5m (150cm) = 366.11

-Using equation 2: Powd = 1.244 x 9.81 x 16L x 1.8m = 351.46

-Using equation 3: Efficiency = [(2)/ (1)] *100 = [683.40/ 366.1] *100 = $\frac{351.46}{366.11}$ * 100 ≈ 95%.

The efficiency of the pump can potentially be high. But this will be based on:

1. The initial height of the water supply (if it is low, output water head will be low as well).
2. The leakages from the ram pump.

The construction of the ram pump needed the following items (1-inch measurements for the prototype and a 20L container to collect the water, were selected):

Table.4 – Items bought and their respective prices (ram pump)

Items needed	Bought or Re-used?
1" PVC pipes (x9, 15cm each)	Re-used
1" T joints	9ghs
1" Elbow	Re-used
1" Ball valve (x2)	12ghs
1" Male Thread Adapter (x2)	15ghs
1" Female Thread Adapter (x2)	15ghs
Water hose	Re-used
Old Voltaic dispenser bottle (20L)	Re-used

Total cost: 131ghs
Budget: 1,000 ghs

4.3. Research Methodology and Procedure

A. Pump CAD Models

Both pumps were designed in Fusion 360. This helped to specify the measurements needed to fabricate. The engineering process requires continuous re-iteration; hence, the team produced several CAD drawings (See Appendix for orthographic projections).

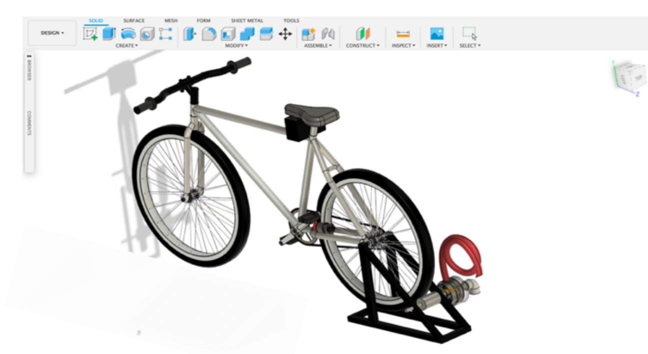

Fig.3 – Completed E-bike (to simulate a motorcycle) pump with the turbine, shaft frame, and water hose

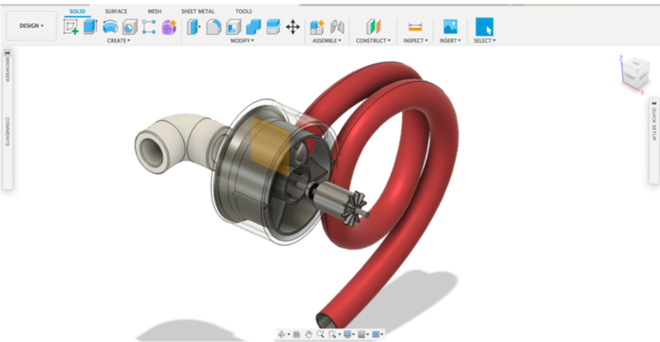

Fig.4 – Bike water turbine (impeller+ shaft + PVC casing and pipe)

Please note that the "E-bike" served as an improvise, as we did not have access to a motorcycle. The pump design also works with normal bikes – in this case the paddling of a person will provide the revolutions per minute. In retrospect, a motor can be directly connected to the pump shaft to reduce losses associated with friction on the wheel – but since this product is intended for people with motorcycles/ bikes, that is not an option. When the shaft spins, it turns the impeller, and this draws water inside the pump (from the hose), and outputs this pumped water through the PVC pipe. Figure 3 displays the CAD model of the completed bike pump, and Figure 5 shows that of the water ram pump.

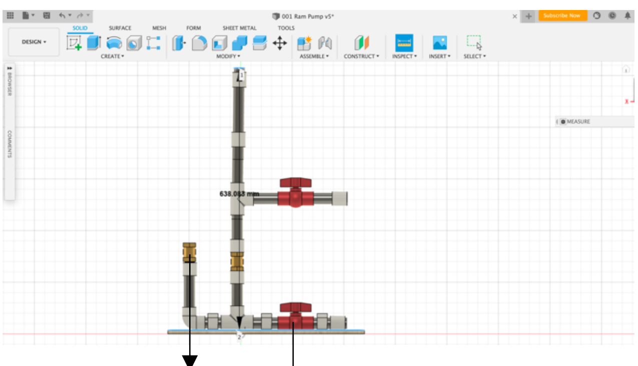

Fig. 5 – Model of ram pump

B. Testing and Re-testing

1) Testing (Simulations)

Bicycle structure simulation: This was intended to test if the bicycle stand would be structurally sound. The team decided to use the SolidWorks software. The total weight of the bike and that of the person sitting on the bicycle, needed to be considered. Table 5 displays the results extracted from SolidWorks.

$$Total\ force = weight\ of\ bicyle(kg) + weight\ of\ human\ sitting\ on\ the\ bike(kg) \quad (5)$$

Table.5 – Material properties of bike stand

Name:	1023 Carbon Steel Sheet (SS)
Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	282.685 N/mm^2
Tensile strength:	425 N/mm^2
Elastic modulus:	205000 N/mm^2
Poisson's ratio:	0.29
Mass density:	7.858 g/cm^3
Shear modulus:	80000 N/mm^2
Thermal expansion coefficient:	1.2e-05 /Kelvin

In simulating, four different forces were used. The weight of the bicycle was 10kg, and various weights of people presumed to be sitting on the bicycle, were used. That is: 30kg, 50kg, 70kg, 110kg. Figure 6 shows the simulations as described below.

1. Force 1 = 10kg + 30kg = 40kg
2. Force 2 = 10kg + 50kg = 60kg
3. Force 3 = 10kg + 70kg = 80kg
4. Force 4 = 10kg + 120kg = 130kg

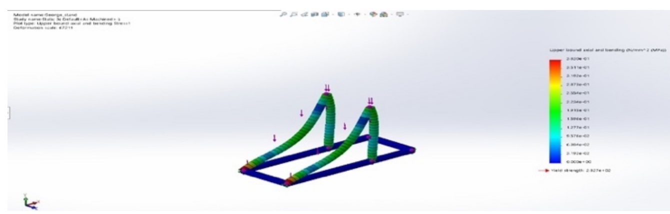

Fig.6- Simulation results for 40N, 60N 80N and 130N respectively

The stand was able to withstand all the forces without any deformation due to its high yield strength i.e. the maximum stress that can be applied before it begins to change shape permanently.

2) Re-testing (Physical Measurements)

Now, in order to compare the functionality and output of both pumps, the team ran a series of tests to ensure that both were subjected to similar operating conditions (each pump was tested for 1min 30s, with readings collected 3 times after every 30s). The team then performed weight tests, volume measurements, and flow rate measurements. The testing circuit was built, and it was interfaced with the online ThingSpeak app (see Figure 7). This was helpful in obtaining pump readings.

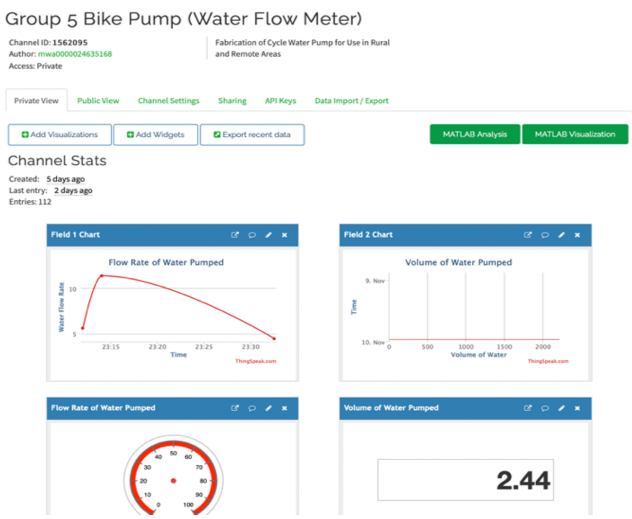

Fig.7 – Bike pump online monitor (flow meter)

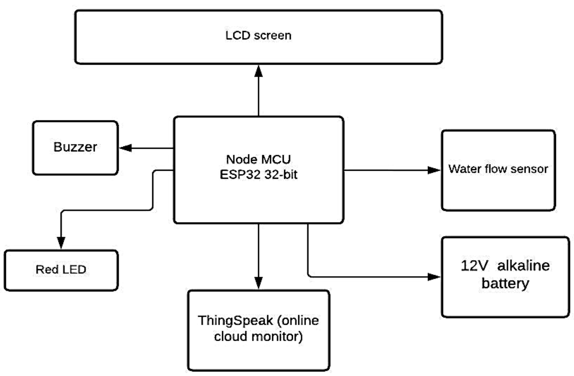

Fig.8 – Measurement circuit - simplified schematic

The testing circuit uses a water flow sensor. So, when water flows through the rotor, the rotor rolls, its speed changes with different rates of flow. The hall-effect sensor outputs the corresponding pulse signal. In so doing, the water flow rate coming out of the pump waws obtained. The microcontroller used was the nodemcu that displayed values on an LCD screen. The buzzer and red LED were used to signal users that they must either put off the ram pump or stop riding the bicycle, because the container in which water is being pumped into, is at capacity. **A great addition to prevent wastage of water.**

1) Primary Design: Bicycle Water Pump

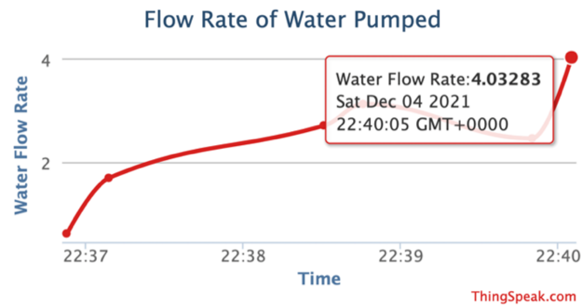

Fig.9a – Graph of flow rates from water bike pump

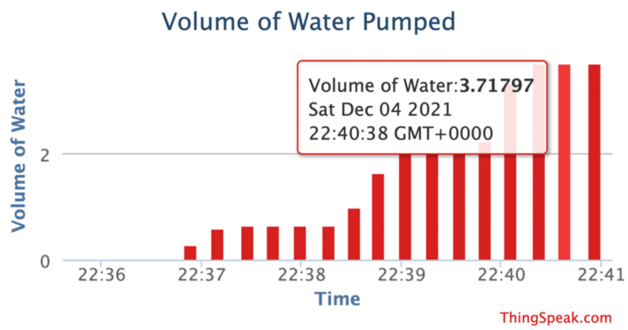

Fig.9b – Graph of volume pumped after 30s (for 1min 30s – 3 times)

At a cycling speed of 60rpm, and a water head of 145cm:

The highest flow rate after 3 tests was recorded:
Highest flow rate = 4.0328 Liters / minute
Volumes collected after 30s: 0.6464, 1.3542, 2.3658

Average volume after 30s = 4.3664/3 = 1.4555 L

2) Secondary Design: Ram Water Pump

The derived results of water flow rate and volume collected after a set time, will help in the process of obtaining suitable calculations to scale up this project.

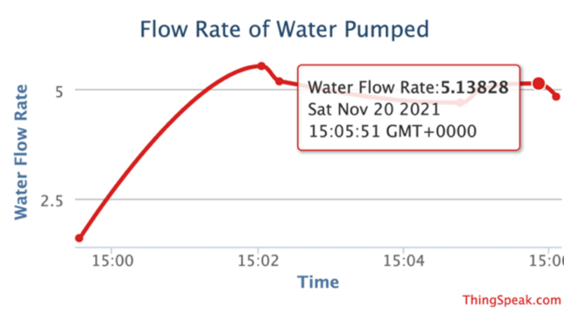

Fig.10a – Graph of flow rates from the water ram pump

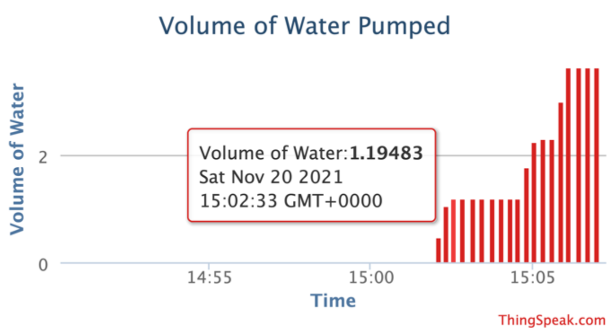

Fig.10b – Graph of volume pumped after 30s (for 1min 30s – 3 times)

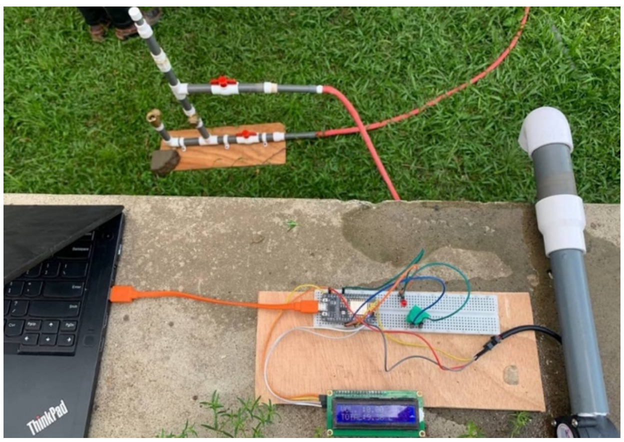

Fig.10c – Testing the output water flow rate and volume of the ram pump

At a testing height of 1.29m:

The highest flow rate after 3 tests (to improve accuracy):
Highest flow rate = 5.2173 Liters / minute
Volumes collected after 30s: 1.1948, 1.1065, 1.3458

Average volume after 30s = 3.64714/3 = 1.2157 L

C. Fabrication

1) Primary Design: Bicycle Water Pump

The impeller was built after carefully selecting the bike pump diameter, as explained in the Calculation and Analysis section. It was 4 inches in diameter, and all of the PVC pipe parts were 1 inch thick. After several simulations, the bike stand was welded together. This resulted in a rigid stand that could support a variety of weights. The bike parts were assembled and tested. Figure 11 depicts the functioning bike pump; the full video can be found in the Appendix.

Fig.11a – The shaft connected to the bike wheel

Fig.11b – Complete bike water pump

2) Secondary Design: Ram Water Pump

Each PVC item was 1 inch in size. The first step was to fit the pieces together. Following testing, PVC Epoxy glue was used to join these parts. The pump was then reconfigured with the water hose and dispenser bottle to pump water from a low-pressure tap - see Figure 12.

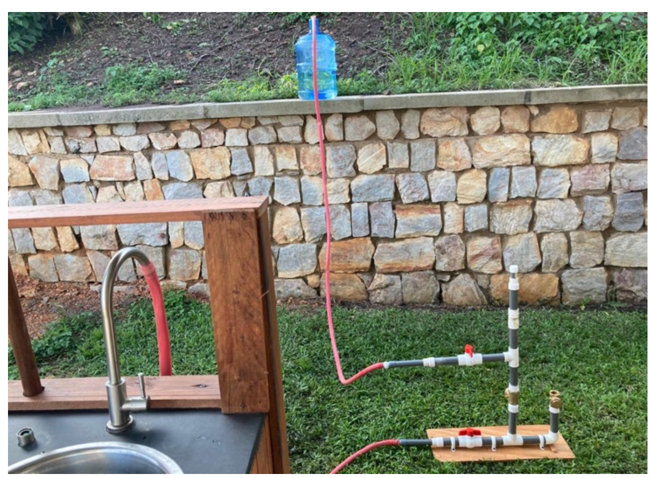

Fig.12 – Completed ram pump filling dispenser tank

5. Scaling Up the Bicycle Water Pump Project

After measuring the bike pump's flow rate, volume, and water head, it will be easier to scale up. An important set of equations were used: Physics *Affinity Laws 1 and 2*.

The Affinity Laws of centrifugal pumps or fans indicate the influence on volume capacity, head (pressure), and/or power consumption of a pump or fan due to change in speed of wheel – revolutions per minute (rpm).

The volume capacity of a centrifugal pump can be expressed as:

$$\frac{Q1}{Q2} = \frac{N1}{N2}\ x\ \frac{D1}{D2} \tag{6}$$

where Q = volume flow capacity ($\frac{m^3}{s}$, gpm, cfm)
N = wheel velocity – revolution per minute - (rpm)
DP = wheel diameter (m, ft) Head or Pressure. The head or pressure of a centrifugal pump can be expressed as:

$$\frac{DP1}{DP2} = \left(\frac{N1}{N2}\right)^2 x \left(\frac{D1}{D2}\right)^2 \tag{7}$$

where DP = head or pressure (m, ft, Pa, psi) constructed the.

Because we are going to maintain the diameter of the pump. D1=D2, they cancel out, and so the equations are simplified to:

$$\frac{Q1}{Q2} = \frac{N1}{N2} \tag{8}$$

$$\frac{DP1}{DP2} = \left(\frac{N1}{N2}\right)^2 \tag{9}$$

-The scaled-down version of the cycle pump delivered water at a height of 145cm (1.45m).
-And the bike rider was paddling at 60 revs per minute.
-In order to increase the water head to 15m (as a scaled-up product), calculations will be made for the rpms necessary to get there – and the volume flow capacity.
*By using equation 4, $DP2 = \left[\frac{N2}{N1}\right]^2$ x $DP1$, and making a change of subject for N2. We get:

$N2 = \left[\frac{DP2}{DP1}\right]^{1/2} x\ N1 = [15/1.45]\ x\ 60 = \mathbf{620.69}$ **rpms.**

Now to calculate the flow rate from this new rpm:

Q1= 4.0328 Litres / min = (6.721e-5) $\frac{m^3}{s}$.
N1= 60 rpm.

*By using equation 3, $Q2 = \frac{N2}{N1}$x $Q1 =$
$\left[\frac{620.69}{60}\right] x$ 4.0328 Litres/min = **41.719 Litres/min or 0.000695 m3/s.**

This means that in order to design (with a maintained diameter of 4 inches), a product that pumps water up to 15m and has a high-water flow rate of approximately 42 Litres/min, the device rpm must be 621 and above. This would prompt an increase in the impeller blades quantity and durability. Plastic blades (as we used for prototyping) will be subject to stress and breakage when pumping water through a 620+ rpm shaft.

This indicates that a motorcycle would work well. As they have nominal revs per minute of about 1000rpms. The only downside is the constant need for fueling (as the user mentioned). The designed water pump accommodates bikes, motor bikes or electric bikes, so it has so much potential to suit many different devices.

6. User Feedback

Following the successful competition of prototype water pumps, the pumps were tested in front of users (those we previously interviewed). Following that, these interviewees completed a product survey form. Please see the appendix for links to the complete customer feedback reports.

7. Limitation and Future Work

The developed pump designs are scaled-down prototypes. They can meet the needs of less-intensive communities (distances or depths of water about 2m away). These designs, however, would be unsuitable for distances of 15m or greater. A water filter was one of the features that was supposed to be included in the pump design. Despite the fact that one was purchased, it was unable to be included in the final design due to project time constraints. It will be implemented in the future with the goal of filtering the pumped water (from wells or underground). The researchers intend to scale up the project to accommodate the long distances that the water must be pumped.

Acknowledgment

Dr. Kenobi Morris deserves special recognition for the knowledge he shared with us and for his insightful feedback. Mr. Prince Coffie, the class teaching assistant, is also thanked for his expert assistance. Furthermore, numerous gratitude is expressed to Mr. Peter, the workshop coordinator, for making the workshop available and assisting in the planning and construction of the prototype. Finally, many thanks to all the interviewees who took the time and patience to contribute to the project.

Appendix

1) Water Pump Orthographic Projections:

https://drive.google.com/drive/folders/1pnlCF-SkObUcQ1idRyr0pJUwDrtCeTrJ?usp=share_link

2) Link to Bicycle Water Pump Video:

- Working shaft and impeller: https://www.youtube.com/watch?v=2fppw4eVYjs
- Complete bike pump: https://www.youtube.com/watch?v=CphJ1AYmpII

3) Complete Water Ram Pump Video:

https://youtu.be/KSkPRFTkgMY

4) New Product Evaluation Survey:

- Water Ram Pump: https://drive.google.com/file/d/1sBej560NyETJz6AFqTkIVU5wWU1-vIz-/view?usp=share_link
- Cycle Water Pump: https://drive.google.com/file/d/1UHBxyXl40NoHdCaZDHu_z35niujlBeUO/view?usp=share_link

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