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DEVELOPMENT OF AN IMPROVED PEDAL POWERED WATER PUMP

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ABSTRACT: The development of an improved pedal powered water pump machine was undertaken with the intention of providing a simple cost solution to the problem of delivery of ground water with relatively less effort. This project analyzes the development of an improved pedal powered water pump for rural use. This development was prompted due to the need for pumping systems that does not use electricity as its power source in under developed area. The system is composed of a reciprocating pump powered by pedaling. The pedal power is being transmitted to the pump via a chain drive. Based on this design, the pump has a cylinder bore of 56cm and a speed stroke of 60 stroke/ minutes. The results of the test carried out showed that the pump discharge was 0.0016 m^3/s at a head of 20*m* using a driving torque of 29.5 Nm with estimated efficiency of 90% which is fairly a good enough result for a pedal operated pumping system. It can be used for irrigation and drinking water purposes. It is more productive operated pumping system and is time saving.

KEYWORDS: Piston, Pump; Water-borehole; Manual-Pedalling; Sprockets; rotating disc; chain-drive.

Nomenclature

A – Cross section area of the pipe
C_b - Basic dynamic load rating
d_1 - Diameter of the smaller sprocket or gear
d_2 - Diameter of the larger sprocket
d_i - Diameter of the shaft
d – Diameter of the piston and cylinder
d_1- Full bore cylinder diameter
d_2 - Piston rod diameter
F – Force exerted on the stroke
g – Acceleration due to gravity
H – Delivery head
K – Number of chain links
K_1 - Load factor
K_2 - Lubrication factor
K_3 - Rating factor
K_b - Combined shock and fatigue factor for torsion
K_t - Combined shock and fatigue factor for torsion
K_s–Service factor
L – Length of the cylinder
L_c - Length of chain
L_d - Design life of bearing
M_b –Bending moment of the shaft
M_t - Torsion moment of the shaft
N_1 – Speed of the smaller sprocket in RPM
N_2 - Speed of the larger sprocket in RPM
N_d - Revolution per minutes of the shaft
P – Pitch of the chain
P_1 – Power transmitted from pedal to pump
P_e – Equivalent Load
P – Rated power
P_d - Design power
P_p - Initial pressure
Q – Flow rate
r – Radius of the pump
S_s - Maximum shear stress
T_1 – Number of teeth on the smaller sprocket
T_2 - Number of teeth on the larger sprocket
T – Torque generated by human pedalling
V_1 - Pitch line velocity of the smaller sprocket
V.R – Velocity ratio of the chain
V – Volume of cylinder
V_o - Velocity
W – Load on chain
X – Centre distance
Z – Constant for all bearing
ρ -Density of water
ε - Pump efficiency
ω - Angular velocity

1.0 INTRODUCTION

The idea of pumping water has been in existence since the evolution of man. Pumping plays a very pivotal role in the day to day existence of mankind and as a result, different methods have evolved over the years to pump or displace water. Water supply has been a very critical issue, mostly affecting the rural areas. Water is one of nature's most important gifts to mankind. It is one of the most essential elements to good health and as such, it should be readily available to everybody. To address this problem, different methods and techniques have been used over the years ranging from man-powered operated ones down to the more efficient one.

Water is a colourless, transparent, odourless, tasteless liquid that forms the seas, lakes, rivers and rain and is the basis of the fluids of living organism. Our ancestors built many of their villages and towns near springs and rivers so that they could get water easily. There is evidence around the world of early peoples using pipes and ditches for moving water to where people lived. They were also digging deep wells and making dams to collect and store water [1].

1.1 Water Distribution Pump

Water-lifting devices fall into two main sub-categories depending on where the water is being lifted from [2]. Groundwater – Rainfall seeps into the ground and collects in an underground reservoir. The upper limit of the reservoir is known as the water-table and can be just below the surface (as with a spring or oasis) or much deeper. The only way to get at this water is via a natural spring or to dig/drill down and use a water lifting device to bring the water to the surface.

Water found on the surface of continents and islands is referred to as surface water. Surface water makes up only one fourth of one per cent, or 0.25%, of the total water found on Earth. This water is found in rivers, streams, lakes, springs and swamps, and is extremely important to the lives of all land dwelling animals, including humans. Water from a lake, river or well may need to be transported to where it is required. Water-lifting devices can be used to make the water more accessible for purposes such as irrigation, drinking or bathing. The water then has to be taken to wherever it is needed – a time consuming and labour-intensive task. What they require is a device to transport the water so that it can be used for irrigation, bathing, drinking etc. Ideally there would be one machine that pumps the water up from the well and pressurises sufficiently to reach everywhere it is needed. However, the vertical distances that the water will need to be pumped may exceed the limits of human performance. It is therefore concluded that bicycle powered water distribution pump will only be required to lift the water from the shallowest wells as its main function is to distribute the water across the surface.

1.2 Principles of Lifting and Moving Water

Water may be moved by the application of any one (or any combination) of five different mechanical principles, which are to a great extent independent of each other [3]. The five principles are as follows:

1. Direct lift - this method of lifting water involves physically lifting water using a container. It is by far the most popular method of lifting water.
2. Displacement -this method of lifting water utilizes the fact that water is incompressible to an extent and as such, it can be effectively displaced.
3. Creating a velocity head -this method of pumping water utilizes the fact that when water is propelled to a high speed, the momentum can be used either to create a flow or to create a pressure.
4. Using the buoyancy of a gas -this method of lifting water utilizes the fact that air or other gas bubbled through water will lift a proportion of the water.
5. Gravity -this method of lifting water utilizes the fact that water flows downward under the influence of gravity.

Clean and accessible water is an essential ingredient for a healthy life globally. Although water holes exist sporadically, gathering enough water to quench the thirst of an entire village proves challenging, especially considering the extremely warm climate which only causes thirst to increase. The method of collecting water from distant water holes also necessitates transportation, often requiring women and children to carry gallons of water over a great distance. In order to combat these complications, a pedal powered water pump was designed and constructed.

The bicycle pedal powered pump can be constructed using local materials and skill. A water system includes a reciprocating pump powered/ operated by bicycle pedal and a driven the reciprocating piston. It works on the principle of compression and sudden release of a tube by creating negative pressure in the tube and this vacuum created draws water from the sump. This bicycle pedal operated pumps water at high rate from well and borehole. Pedal powered reciprocating water pump provides drinking water and irrigation in remote area where electricity is not available. Pedal powered reciprocating water pump is not only free from pollution but also provide healthy exercise. Pedal powered reciprocating water pump reduces the rising energy costs. Pedal Powered reciprocating water Pump is designed as portable one which can be used for irrigation in various places. It consists of a reciprocating pump operated by pedal power. The reciprocating pump is positioned on it stand in such a way that driven piston shaft of the reciprocating pump is butted to bicycle sprocket. By pedalling the bicycle, the bicycle sprocket rotates; thereby make the reciprocating pump to discharges water from the sump [4].

2.0 MACHINE DESCRIPTION

The main components of the machine include parts of the transmission unit (bicycle), pump unit and piping unit; the bicycle unit consist of chain drive, sprocket, pedal, gear, bicycle frame and wheel while the pump unit is made up of pump cylinder, piston, connecting rod, cylinder cap, seal, sprocket, rotating disc, shaft, bearing, bolt and nut, hub, pump frame, adjuster and column stand while the piping system consist of the inlet and the outlet valves. The pump is powered by bicycle pedal. The isometric view of the developed pedal powered water pump is shown in Fig. 1.0 below.

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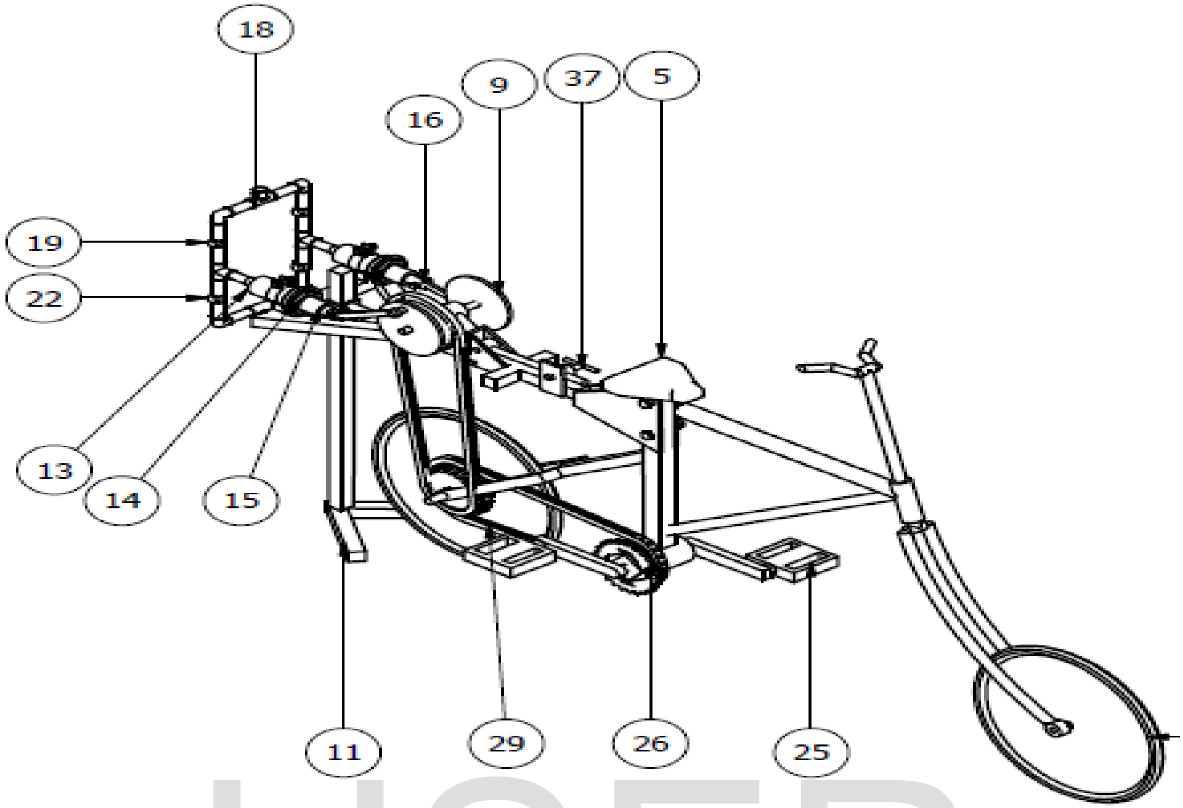

Fig. 1.0: Isometric View of Developed Pedal Powered Water Pump

In Fig. 1.0, the following parts are shown: 5- seat, 6- tyre, 9- rotating disc, 11-stand, 13-cylinder pump, 14- cylinder cap, 15- piston, 16 – connecting rod, 18 – discharge pipe, 19 – outlet valve, 22 – inlet valve, 25 – pedal, 26 – gear, 29 – chain, 37- Adjuster.

3.0 DESIGN COMPUTATIONS

The chains are made up of number of rigid links which are hinged together by pin joints in order to provide the necessary flexibility for wrapping round the driving wheels. These wheels have projecting teeth of special profile and fit into the corresponding recesses in the links of the chain. The toothed wheels are known as sprocket wheels or simply sprockets. The sprockets and the chain are thus constrained to move together without slipping and ensures perfect velocity ratio. The velocity ratio determined from the equation given by [5].

$$V.R = \frac{N_1}{N_2} = \frac{T_2}{T_1} \qquad (1)$$

Where,
N_1 = Speed of rotation of smaller sprocket in rpm,
N_2 = Speed of rotation of larger sprocket in rpm,
T_1 = Number of teeth on the smaller sprocket and
T_2 = Number of teeth on the larger sprocket. Given that T_1 = 18 and T_2 = 45. However velocity ratio is 2.5 ≅ 3

The number of chain links K is given by [5].

$$K = \frac{T1+T2}{2} + \frac{2x}{p} + \left(\frac{T2-T1}{2\pi}\right)^2 \frac{p}{x} \qquad (2)$$

Where,
T1 = Number of teeth on the smaller sprocket, T2 = Number of teeth on the larger sprocket, **p** = pitch of the chain and ***x*** =centre distance
The pitch of the chain to be used for this design is obtained from the Characteristics of Roller Chains According to IS: 2403-1991 which is 08. Given that T1 = 18, T_2 = 45, p = 1.27cm and x = 50cm. Therefore the number of chain links K is 111.

The length of chain (L) is the product of the number of chain links (K) and the pitch of the chain (P)

L = K × P (3)

Given that K = 111 and p = 1.27cm. However the length of chain is 140mm

The power transmitted by the chain is given by:

Design power = Rated power × service factor (4)

Service factor $K_s = K_1 \times k_2 \times k_3$

Where,

K_1 = Load factor, k_2 = Lubrication factor and k_3= Rating factor: Given that K_1 = 1, k_2= 1.5 and k_3 =1.5. Therefore K_s is 2.25 and Design power is 1800W

The torque required for driving the pump during pedaling is obtained by:

The power transmitted from pedal to the pump is given by

$P = \frac{2\pi NT}{60}$ (5)

Where,

N = speed of the pump during manual pedaling and T= torque required to drive the pump. Given that P = 1800w, π= 3.142, N = 80. Therefore T = 214.7Nm

The torque generated by human pedaling is obtained by:

Recall that the power transmitted from pedaling to the pump is given by

$P = \frac{2\pi NT}{60}$

Where,

N = pedaling speed and T = torque developed by pedal

The rated for healthy human being is approximately 250 watts [5]. Hence, P = 250W, π = 3.142, N= 250. Therefore torque generated by human pedaling is 29.84Nm

We know that pitch circle diameter of the smaller sprocket or pinion and the pitch circle diameter of the largest sprocket or gear

d_1 = p cosec $\left(\frac{180}{T_1}\right)$ and d_2 = p cosec $\left(\frac{180}{T_2}\right)$ .... … (6)

where,

p = pitch and T_1 = number of teeth on the smaller sprocket or gear and T_2= number of teeth on the larger sprocket. Given p = 12.7, T_1= 18 and T_2= 45. Therefore d_1= 0.073m and d_2 = 0.182

Therefore, pitch line velocity of the smaller sprocket

$V_1 = \frac{\pi d_1 N_1}{60}$ (7)

where,

d_1 = diameter of the smaller sprocket, N_1= speed rotation of the smaller sprocket: given π = 3.142, d_1 = 0.073m and N_1= 80 rpm. Hence V_1 = 0.31 m/s

The load on the chain is designed as follows,

Load on the chain W = $\frac{Rated\ power}{pitch\ line\ velocity}$ (8)

Where,

pitch line velocity $V_1 = \frac{\pi d_1 N_1}{60}$ = 0.30m/s and rated power = 800w. Therefore

Load on the chain is 2580N

3.1 Design for solid shaft

The shaft is acted upon by weight of the two rotating disc, bearing the connecting rod and it is contained in the hub. The shafts transmit the rotating motion of the chain to the connecting rods. Therefore in order to safeguard against bending the diameter of the shaft was determined form the equation given by [6].

$d^3 = \frac{16}{\pi s_s}[(K_b M_b)^2 + (K_t M_t)^2]$^ 0.5 (9)

Where,

d =diameter of the shaft, s_s = Maximum shear stress, K_b =Combined shock and fatigue factor for bending, M_b = Bending moment of the shaft, M_t = Torsion moment of the shaft and K_t = Combined shock and fatigue factor for torsion: Given that K_b = 1.5, M_b = 5.355, K_t = 1.2 and M_t = 100.255. Therefore, a mild steel rod of diameter 24.85mm was used for the shaft

3.2 Selection of bearings

A bearing is a machine element that constrains relative motion between moving parts to only the desired motion. The design of the bearing may, for instance provide for free linear movement of the moving part or for free rotation around a fixed axis or it may prevent a motion by controlling the vectors of normal forces that bear on the moving parts.

The basic load ratings were determined using the equation below as:

$$C_b = P_e(\frac{60L_dN_d}{10^6})^{\wedge 1/z} \quad [6] \quad (10)$$

Where,

C_b = basic dynamic load rating, P_e= equivalent load = 125.30N, L_d = design life of the bearing = 30000hrs, N_d= revolutions per minutes of shaft = 300rpm, Z = constant for all bearing = 3. Hence C_b = 6300N = 6.3kN. A self -aligning ball bearing number 205 is selected for both sprockets from the Basic static and dynamic capacities of various types of radial ball bearings table. Therefore a bearing of 25mm bore was selected.

Design for The volume of the pump is designed as follows,

Volume = Area × length (11)

Where,

d = diameter of the piston = 53mm = 0.053m, Length l = 205mm= 0.205m and Area = $\frac{\pi d^2}{4} \times l$. Therefore Volume V is 0.00045m^3

Design for The force on the cylinder is designed as follows,

The force exerted on in stroke can be expressed as

$$F = \frac{p\pi(\ d^2{}_1 - d^2{}_2)}{4} \quad (12)$$

Where,

p = Initial pressure (N/m²), $d_{1=}$ Full bore cylinder diameter (m),d_2 = piston rod diameter (m): Given p = 1 bar (assumed), π = 3.142, $d_{1=}$ 56mm = 0.056m, and $d_{2=}$ 53mm = 0.053. Therefore force exerted on the cylinder is 26.69N/m

3.3 Construction Process

The fabrication of this research work was carried out at the Central Engineering workshop of The Federal University of Technology, Akure, Ondo State, Nigeria. Figure 2 below shows the exploded view of the machine, while Figure 3 is the Isometric view of the machine.

The cylinder and the piston was fabricated from an aluminium rod of diameter 35mm and length 155mm which was machined to 30mm diameter on the lathe. The shaft was fabricated from a mild steel rod of 30mm and length 50mm which was then machined to 25mm on the lathe. The rotating disc was fabricated from 80mm ×80mm mild steel sheet grinded to a diameter of 70mm using electric grinding machine.

The support was fabricated from mild steel of 4mm thickness and 40mm×40mm area and length 985mm. It was welded using electric arc welding method. Following the design specifications, mild steel bracing of length 100.5mm was cut and welded to the support to serve as reinforcement for the frame. The frame was fabricated from mild steel of 4mm thickness and 40mm×40mm area and length 805mm was cut and welded.

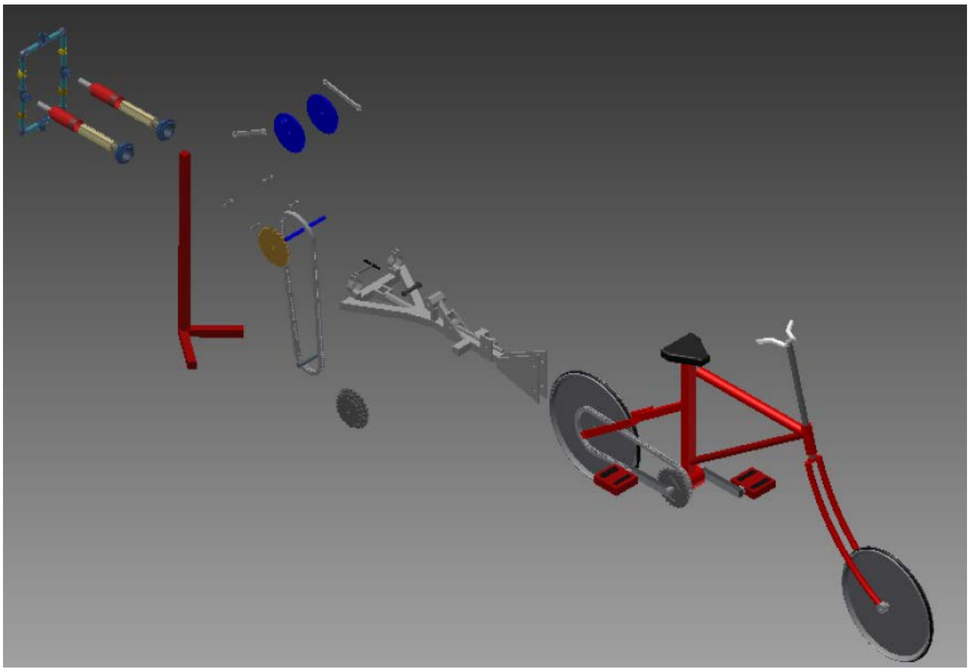

Fig. 2: The exploded view

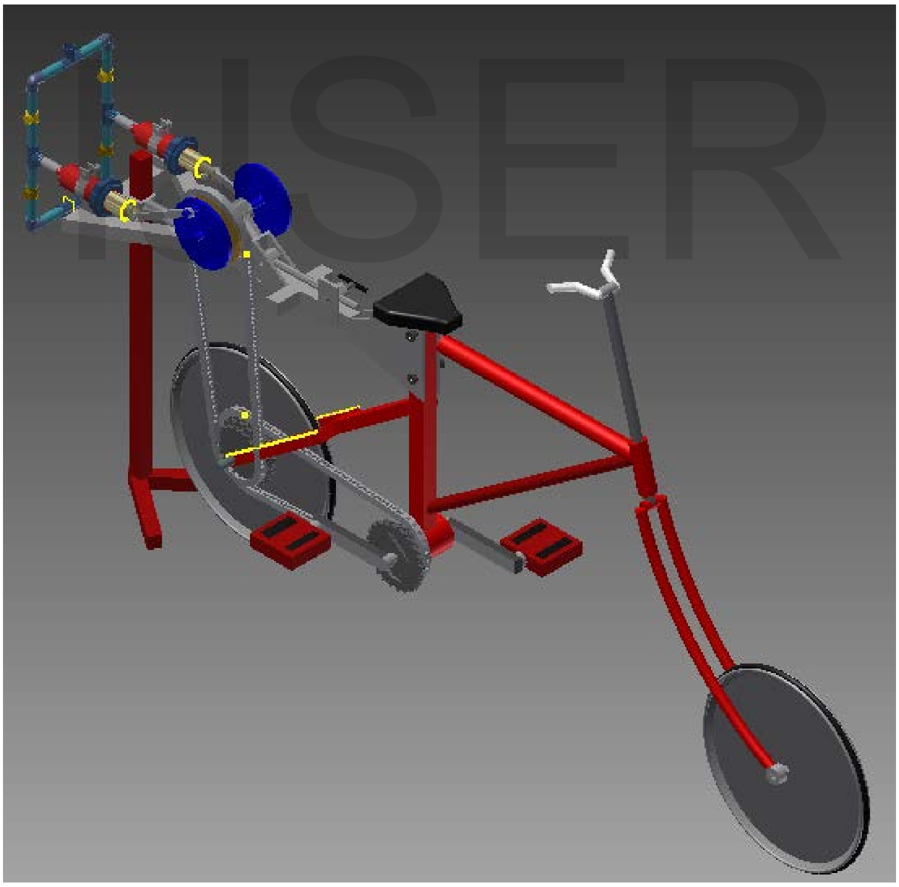

Fig.3: Pictorial view of the Machine

Fig.4: Pedal Powered water pump Machine developed

The materials for fabrication of the pedal powered reciprocating pump and their specifications are presented in Table 1.

Table 1: Materials for fabrication of the pedal powered reciprocating pump and their specifications

S/N	Materials	Specifications	Quantity
1	Bolts and nuts	M14	6
2	Welding electrode	Gauge 10 mild steel	$^1/_2$
3	Mild steel pump frame	4mm thickness 805mm length	4
4	Cast iron hub		1
5	Mild steel support	4mm thickness 985mm length	3
6	Mild steel rotating disc	Φ70mm	2
7	Connecting rod	70mm length	2
8	Mild steel bracing	90mm length	2

4.0 PERFORMANCE EVALUATION

The pump was operated to evaluate its performance. The pump was used to pump water from a well at a head of10m and the discharge recorded was 0.0016 m^3/s.

Further test was carried out by pumping water for longer period of time at different time intervals of 20 seconds. And the results obtained from the test are presented in Table 2.

Table 2: Test Results Obtained

Volume (m^3)	0.02	0.025	0.03	0.035	0.04	0.045	0.05	0.055	0.06
Time (sec)	20	25	30	35	40	45	50	55	60

5.0 DISCUSSION OF RESULTS

The machine developed when subjected to discharge volume of water ranging from $0.02m^3$ to $0.06m^3$at time of 20seconds to 60seconds respectively as shown in Table 2. As the time of discharge increases the volume of water discharge increases as well. Even though, the system is energy consuming, pedalling is recommended for individuals as a form of exercise to burn calories in the body. This prompts the use of treadmills and bicycles for this purpose. From the results obtained, using pedal powered water pump at places where wells and bore holes are very deep and to fetch water manually is cumbersome and strenuous is suggested. Also at a higher level it can be used for irrigation and drinking water purposes. For pumping more water, electric pump is needed, but where electricity is not available pedal-powered water pump can be of great use.

6.0 CONCLUSION

The bicycle powered water pump is a very advantageous especially for rural areas. The problem of energy crises is very big in Nigeria. By the use of this manually pedal powered pump we save electricity and we supply the water in irrigation and other agricultural uses. When we drive a bicycle the wheel of bicycle are rotated so we can provide another chain over the wheel in which the sprocket is mounted on the shaft containing the rotating disc and a piston rods of the pump, the rotating disc rotate due to rotating of the wheel with rotation of sprocket . So we operate the pump and deliver the water at a particular head, create a simple and efficient way of pumping water, utilizing a human powered bicycle for communities where electricity is not available or impractical, isolated community with or without electricity in need of efficient water pumping.

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