DESIGN AND FABRICATIONS OF A GRAVITATIONAL VORTEX HYDRAULIC TURBINE

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DESIGN AND FABRICATIONS OF A GRAVITATIONAL VORTEX HYDRAULIC TURBINE

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CERTIFICATION

This is to certify that the project titled “Design and fabrication of a gravitational hydraulic turbine” was carried out by Otutuama Oghenewegba Micheal, Oyakhilome Godstime Ojakorotu Prince and Kanuhor Oghenekevwe Victor with matriculation no ENG1407010, ENG1403812, ENG1407002 and ENG1403783 respectively of the Department of Mechanical Engineering, Faculty of Engineering, University of Benin, Benin City.

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DEDICATION

We dedicate this project to God almighty for all his mercies and grace upon us and to our loving parents for their love and care during our stay in university of Benin.

ACKNOWLEDGEMENT

We are grateful to the almighty God for his uncommon and sacrificial love toward us. His unfailing grace and strength that had seen us through. We wish to express our utmost gratitude to our project supervisor DR. Collins Chike Kwasi Effah for his immense guidance and assistance during the course of this work, God bless and keep you sir, thanks also goes to the Head of Department Dr. O. O Ighodaro, academic and non-academic staffs in Mechanical Engineering. Also to the lecturers who scrutinized our work during mock defense to ensure that the project is on the right path, to the numerous sources quoted here in and used as authority in certain aspects of the project. We wish to extend our unfeigned gratitude to our parents Mr. & Mrs. Otutuama, Mr. & Mrs. Oyakhilome, Mr. & Mrs. Ojakorotu and Mr. & Kanuhor for their numerous support to us in the pursuit of our academic dreams.

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NOMENCLATURE

b: Blade widthm

B: Water way widthm

D: Runner diameter m

g: Gravitational acceleration m/s2

h: Water depth m

hd: The difference in height between the bottom surface of tank and the bottom surface of downstream waterway m

H: Effective head (m)

L: Angular momentum per unit blade width and unit time N·m/mm·s

n: Rotational speed min−1

s: Specific speed min−1, kW,m (= n(P/1000)1/2/H5/4)

P: Turbine output W(= 2πnT/60)

q: Flow rate per unit blade width m3/mm·s

Q: Flowratem3/s

T: Torque N·m

u: Circumferential velocity m/s

V: Absolute velocity m/s

VF: Volume fraction of water

w: Relative velocity m/s

Greek Letters

β: Relative flow angle ∘

b: Blade angle ∘

η: Turbine efficiency (= $P/\rho g Q H$)

θ: Circumferential angle ∘

ρ: Density of water kg/m3

w: Wate rarea

SUBSCRIPTS

1: Runner inlet

2: Runner outlet

3: Upstream

4: Downstream

a: Axial component

h: Hub

r: Radialcomponent

t: Tip

u: Circumferential component

ABSTRACT

Gravitational water vortex power plant is a green technology that generates electricity from alternative or renewable energy source. In the vortex power plant, water is introduced into a circular basin tangentially that creates a free vortex and energy is extracted from the free vortex by using a turbine. The main advantages of this type of power plant is the generation of electricity from ultra-low hydraulic pressure and it is also environmentally friendly. Since the hydraulic head requirement is as low as 1m, this type of power plant can be installed at a river or a stream to generate electricity for few houses. It is a new and not well-developed technology to harvest electricity from low pressure water energy sources. There are limited literatures available on the design, fabrication and physical geometry of the vortex turbine and generator. However this projects focus specifically on the design and fabrication of hydraulic vortex turbine, Determination of its flow characteristics and performance evaluation of vortex turbine.

CHAPTER ONE

INTRODUCTION

1.1 Background To Study

The need for cleaner sources of energy has become a major global issue owing to the effects of global warming and environmental pollution brought about by conventional fossil fuel usage. To this end and coupled with the ever-increasing energy demand, efforts have been made to develop alternative sources of energy (renewable). Renewable energy such as hydropower has become one of the most demanded sources of energy for its clean generation. Low head hydropower plant is demanded in area which cannot see grid extension due to difficult geographical terrain and other reasons. Water vortex power plant is one of such low head turbine in which the mechanical energy of free surface flowing water is converted to kinetic energy by tangentially passing the water to a basin, which forms a water vortex.

Water energy being a clean, cheap and environment friendly source of power generation is of great importance for sustainable future; however, designing such energy system to harness energy from water is usually a major challenge. Energy from water can be harnessed using different approaches, some of which include: hydrostatic and hydrokinetic methods. Hydrostatic approach is the conventional way of producing electricity by storing water in reservoirs to create a pressure head and extracting the potential energy of water through suitable turbo- machinery (Sagar Dhakal et.al, 2014). In hydrokinetic approach, the kinetic energy inside the flowing water is directly converted into electricity by relatively small scale turbines without impoundment and with almost no head, which is usually placed inside a river and activated by the water current. Gravitational water vortex turbine is an ultra-low head turbine which can operate in a low head range of 0.7–2 m (Zotlotere, 2013).

The concept of micro hydropower system is a promising technology in renewable energy. Micro hydro power systems are capable of generating electricity up to a capacity of 100 kW. The energy in rural, remote and hilly areas is inadequate, poor and unreliable supply of energy services, micro hydropower able to provide rural area where grid extension is too costly and consumers have low incomes. In general, hydropower plants produce no air emissions but in most cases affect the water quality, wildlife habitats and especially prevent the fish migration, gravitational water vortex power system which is classified as micro hydropower can provide a solution for this environmental problem, it is a horizontal form of the hydroelectric dam. The benefits of using an artificially induced vortex above gravity-accelerated water increases efficiency, decreases cost, and not only lowers the negative impact on the environment, but actually increases the sustainability and health of the river as a whole (O. Paish, 2002).

The Ikpogba river has been identified as the possible placement for an alternative renewable energy source and this project tends to use that location as a case study.

1.2 Problem Statement

Due to the issue of global warming, environmental pollution and the sky-rocking price of oil, it has become imperative to source for an alternative clean energy to overcome the present challenge. Besides these environmental crises, the Nigeria epileptic power supply has made it an economic demand to source for alternative designs to produce power. In this context, the distribution mode of power generation seems to be inevitable as this is seen as one method of solution to the energy crisis faced in Nigeria. Designing a vortex turbine as a distributed power generation plant will go a long way in tackling some of these challenges.

1.3 Aim and Objectives

The aim of this project is to design a micro vortex turbine to produce electricity using locally sourced materials.

This is to be achieved by meeting the following objectives:

I. Determine the flow characteristics of the case study
II. Design a vortex turbine using the data available from survey
III. Performance evaluation analysis of the vortex turbine i.e (theoretical/actual analysis).

1.4 Significance of Study

This study is significant in the Nigeria energy sector which has lots of energy challenges especially in generation and distribution. The vortex micro water turbine finds major applications in the distributed generation (DG)

1.5 Scope and limitations

The scope of this work entails the basic theory of vortex turbine, its application and a micro design of energy generating system using locally sourced materials and is limited to the Ikpoba hill river as case study.

1.6 Methodology

The approach for this study includes; to carry out a suitable geographical/location siting, to obtain detailed characteristics of Ikpoba hill river. The micro vortex turbine will be designed using Solid-works engineering software. Performance evaluation of the vortex turbine will be conducted in order to ascertain the actual power produced and possible scaling. Laboratory test of the gravitational vortex turbine will be experimented.

CHAPTER TWO

LITERATURE REVIEW

2.1 The physics of micro hydropower

Based on the conversion of energy, micro hydro power energy transfer is shown in Figure 2.1 below;

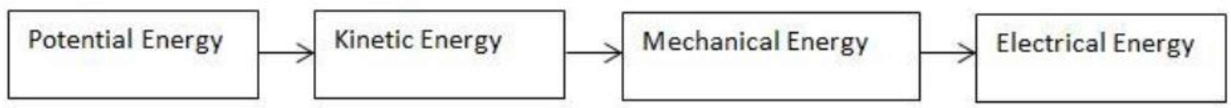

Figure 2.1 Micro hydro power energy transfer block diagram.

1. **Potential energy :**

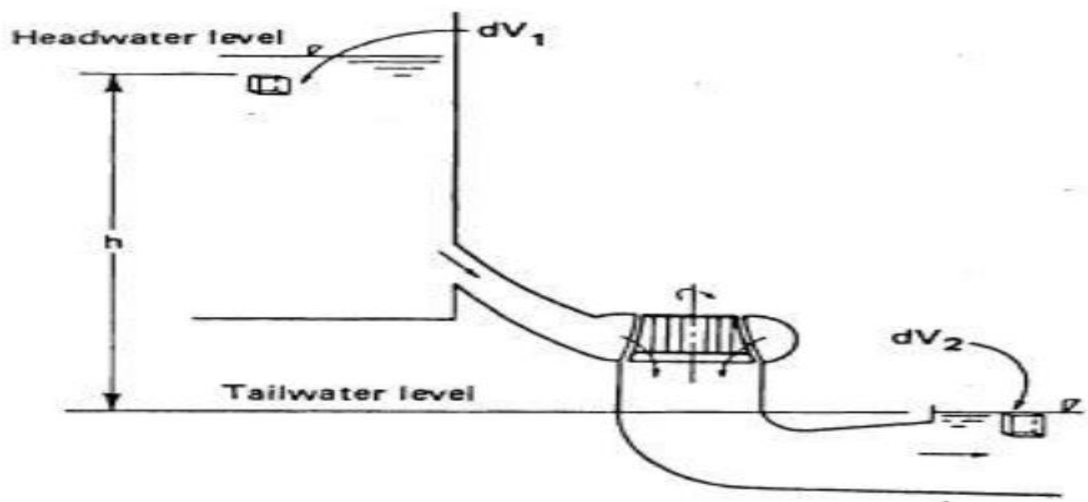

Figure 2.2 Micro hydropower design

The most fundamental knowledge when hydropower is involved is the head level. Head level is defined as the difference between the maximum height of water to the minimum height of the water, marked *h* in the diagram above.

Head level is also directly proportionate to the potential energy. A high head level would mean that the potential energy for that system is very high. The effective head is the difference between the energy head at the entrance to the turbine and the energy head at the exit of the draft tube. When the volume of waters moves from the maximum level at dV1 to the minimum level of dV2 for a height of h, work will be produced and defined by the equation;

$$Work = Force * distance$$

$$\boldsymbol{W = \rho g V h} \qquad 2.1$$

Using the equation for work, it is possible to calculate the theoretical power output of the hydropower system. This is done by differentiating the work equation with respect to time.

$$Power = Work/Time \qquad 2.2$$

$$dP = dW/dT \qquad 2.3$$

$$= \frac{\rho g V h}{t}$$

$$= \rho \, g \, \frac{V}{t} \, h$$

$$P = \rho g Q h \qquad 2.4$$

Where Q is the volumetric flow rate through the turbine. Power is measured in units of Watts.

2. Kinetic energy ;

As the water hits the impulse vanes, a dynamic force will exist in order for the vanes or buckets to start rotating. The rotation of the vanes converts the potential energy to kinetic energy. The force on the moving vane or bucket by a jet of water is derived as the equation of force:

$$F = Wv(1 - m\cos\theta) \qquad 2.5$$

W = Weight of the water striking the vane (N)

v = relative velocity of water with respect to moving vanes (m/s)

m = coefficient for loss of velocity moving across vane

θ = angle of deflection of the jet from its original direction (°)

g = acceleration due to gravity (m/s^2)

The relative velocity can be found using the equation:

$v = V - u$ 2. 6

V = absolute velocity of the water (m/s

u = absolute linear velocity of the bucket (m/s)

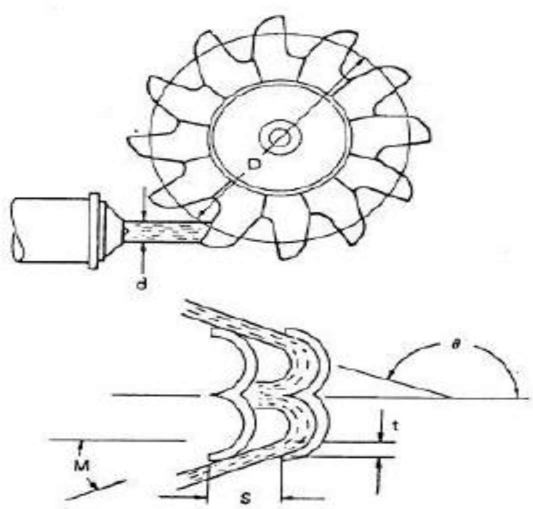

Figure 2.3 Manes used in runners

The torque that is exerted on the vanes by the jet of water is the product of the force and the radius of the lever arm on which the water is acting.

$T = Wvr(1 - m\cos\theta)$ 2.7

Once the value for torque has been obtained, it is now possible to calculate the theoretical power that is exerted by the wanes. Power is simply the product of torque and angular velocity of the runner in rad/second.

$P = T\omega$ 2. 8

Once the wheel diameter is determined, the bucket spacing is calculated. Buckets that are too close will not have a high weight of water hitting on the vanes. When the water weight is low, this will reduce the force on the bucket. If the buckets are placed too far apart, water would flow through and only very little energy will be extracted from the system. Bucket spacing, s, is calculated using:

$$s=\pi dnb \tag{2. 9}$$

In order for the runner to perform efficiently, the water should leave the runner in an axial direction and with a very small absolute velocity. However, this will not be possible as to do so would mean obtaining completely axial flow at all the gate openings. Hence, the absolute velocity of the water is considered as the water exits from the runner to be equal to the water discharged divided by the area of the draft tube. The required height of the passage at the entrance of the runner is expressed as;

$$B=A1\pi C1D1\sin\alpha \tag{2. 10}$$

B = height of the passage (m)

A= cross sectional area of water passage at right angle to the direction of flow (m^2)

C = Coefficient at 0.95

D = Diameter of circle at the runner’s entrance (m)

α = guide vane angle (°)

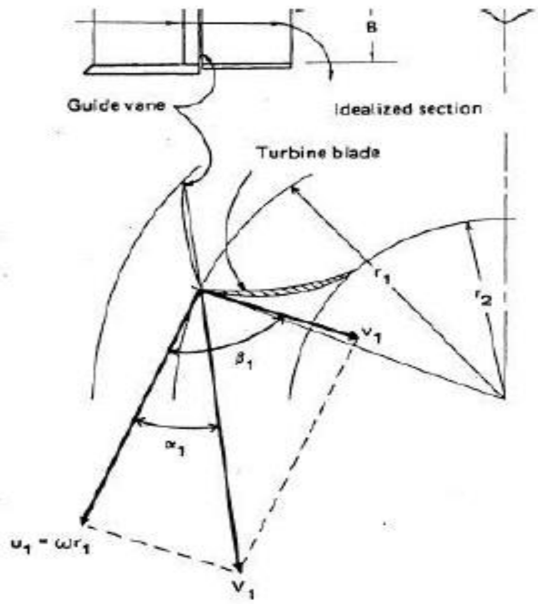

Figure 2.4 Water action on runner reaction

2.2 MICRO HYDROPOWER TURBINES SYSTEMS

Micro hydro turbines have a rapid response for power generation and so the power may be used to supply both base load and peak demand requirements on a grid supply. Power generation efficiencies may be as high as 90% (John Twidell et. al). Water turbines generate very reliable power with very simple designs, turbines are of two types: impulse and reaction turbines, each suitable for different types of water flow. Figure 2.5 shows the various types of hydropower turbines.

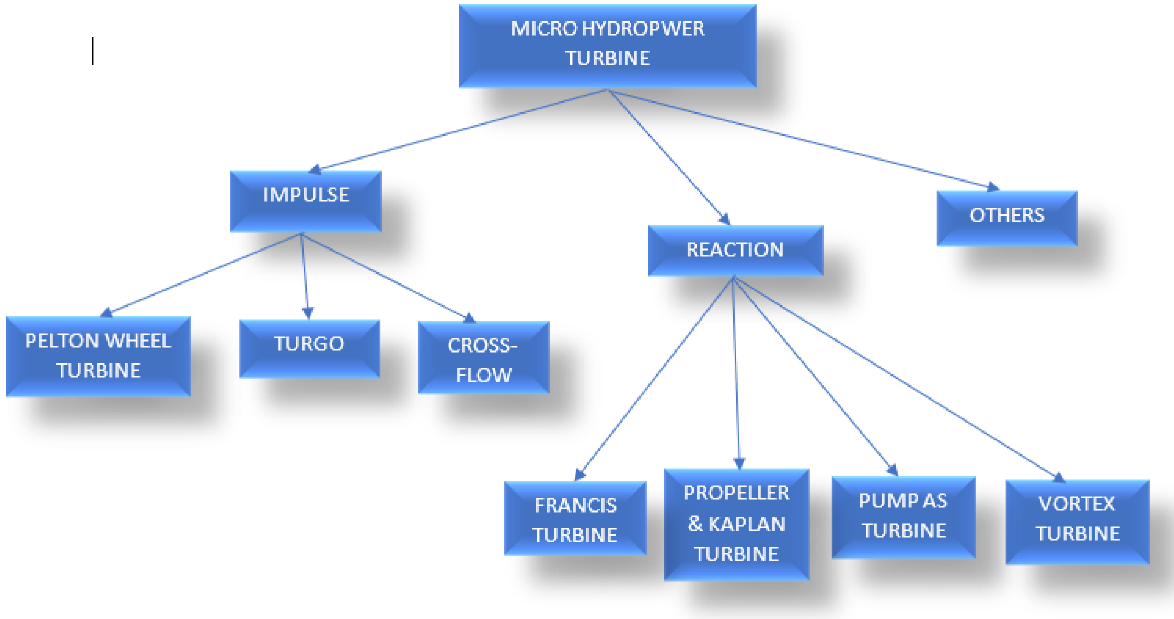

Figure 2.5 Micro hydro turbines systems

2.2.0: Impulse Turbine

This is a commonly used scientific term and describes a force multiplied by the amount of time it acts over. In the context of hydropower machines, it is equivalent to a momentum exchange process, when a jet or stream of water impacts upon a relatively slow moving bucket or blade. Examples of such hydropower machines include highly efficient pelton turbines, and some basic forms of undershot waterwheel. Importantly, the multiple blades or vanes of these machines are not being continuously acted upon, instead rotating about an axle, being sequentially introduced into, and then removed from the jet or stream of water.

2.2.1 Turgo Turbines

By 1920 Gilbert Gilkes Ltd invented Turgo turbine (Figure 2.6) (S.J Williamson et. al, 2013). They are commonly used as high and medium head impulse turbines (Paish, 2002), recently they can be used for all head categories, Energy Systems & Design Ltd. (Ltd, 2019) produces a Turgo turbine stream engine which can be operated between 3 and 150 m head. S.J. Williamson *et al.* (S.J

Williamson et. al, 2013) developed model of a single-jet Turgo turbine at low heads of 3.5 m down to 1 m to improve the design and set up the parameters. The Turgo can handle significantly higher water flow rates (B.R. Cobb et. al, 2013) (S.J Williamson et. al, 2013), allowing for efficient operation in lower head ranges because it can generate significant power by using more water with less head (B.R. Cobb et. al, 2013) (Davis, 2005).

Figure 2.6 Turgo Turbines

2.2.2 Pelton Turbines

In a Pelton turbine as shown in Figure 2.7 , water jets from nozzles strike cups or buckets arranged on a circumference of a runner or wheel, causing the wheel to rotate (Davis, 2005) (A. Furukawa et. al, 2010). A Pelton wheel has one or multi free jets. Pelton turbines are suited for high head, low flow applications, recently Pelton turbines can also be used for small and Micro hydropower systems. (A. Furukawa et. al, 2010) (T.K. Ghosh et. al, 2011) (Voith Hydro, 2013). For these systems, a single water jet is typically used (Davis, 2005).

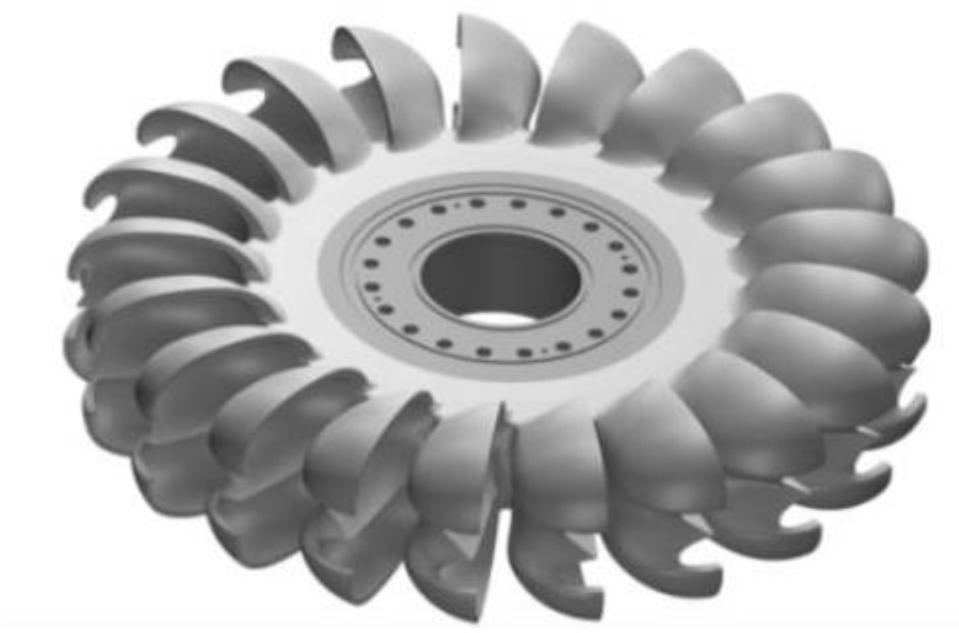

Figure 2.7 Pelton turbine

2.2.3 Cross Flow Turbines

A cross-flow turbine is designed by Ossberger Co, so it known as an Ossberger turbine, is shaped like a drum and uses an extended, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner (T.K. Ghosh et. al, 2011). The cross-flow turbine allows the water to flow through the blades twice. During the first pass, water flows from the outside of the blades to the inside; the second pass is from the inside back out. These types of turbines can be used both in horizontal and vertical orientations (Figure 2.8). These turbines can familiar with micro hydro, higher water flow and lower head than the Pelton turbine (T.K. Ghosh et. al, 2011) (Co., 2011) (S. Khosorowpanah et. al, 1988).

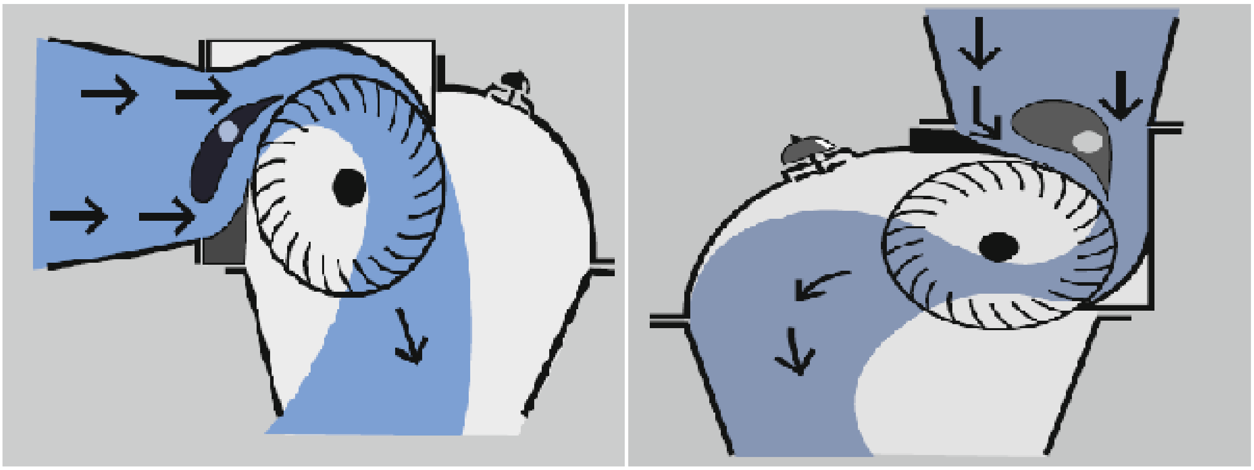

Figure 2.7 Cross-flow turbine

2.3 Reaction Turbines

Reaction Turbines have a better performance in low head and high flow sites. They have not nozzles, the blades project radially from the periphery of the runner are formed and mounted so that the spaces between the blades have, in cross section, the shape of nozzles (Jimenez, 2009) (T.K. Ghosh et. al, 2011). A reaction turbine generates power from the combined action of pressure and moving water (T.K. Ghosh et. al, 2011) .In the slow operating speed, the efficiency of reaction turbines is better than the impulse turbines (Jimenez, 2009). Also Reaction turbines are generally preferred over impulse turbines when a lower head but higher flow is available (A. Furukawa et. al, 2010) (T.K. Ghosh et. al, 2011).

2.3.1 Francis Turbines

A Francis turbine has a runner with fixed buckets (vanes), usually nine or more. Water is introduced just above the runner and all around it and then falls through, causing it to spin (T.K. Ghosh et. al, 2011) (Voith-Siemens, 2013). Besides the runner, the other major components are a scroll case, wicket gates, and a draft tube The cross-sectional view of a Francis turbine is shown in (Figure 2.9) .The Francis turbines have a good performance for micro hydropower sites (Voith-Siemens, 2013) (A. Ruprecht et. al, 2002) (R. S Resiga et. al, 2006).

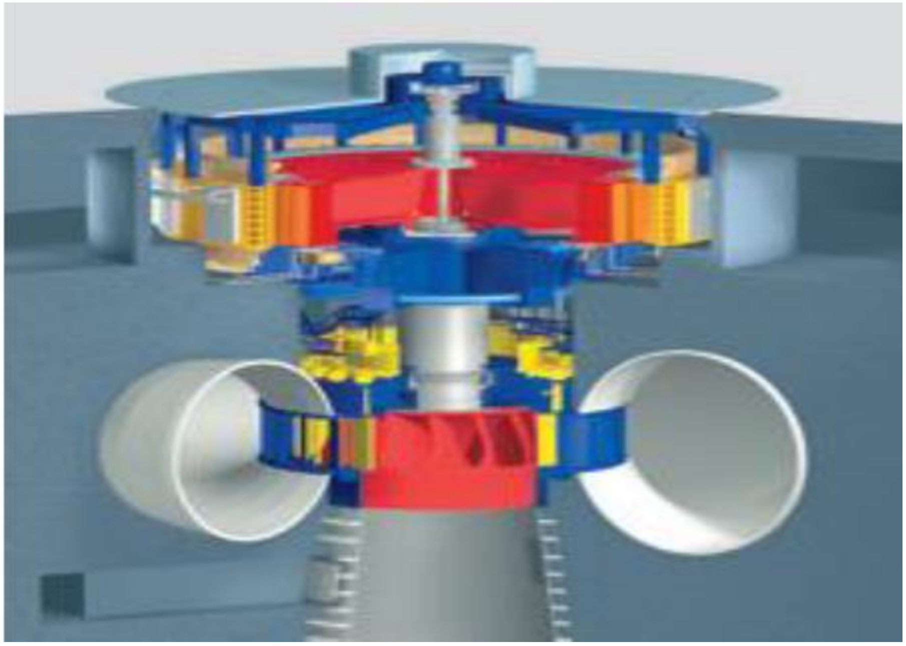

Figure 2.8 Francis turbine

2.3.2 Axial Flow Turbines "Propeller and Kaplan Turbines"

Most of the reaction turbines are a propeller type turbine. A propeller turbine generally has a runner with three to six blades in which water impinges continuously at a constant rate. The pitch of the blades may be fixed or adjustable. The major components besides the runner are a scroll case, wicket gates, and a draft tube see (Figure 2.10) (T.K. Ghosh et. al, 2011). The propeller turbine design was originally motivated by the need to develop high specific speed machines for use in relatively low head situations where it would be uneconomic to use a Francis turbine (P. Singh et. al, 2011).

Viktor Kaplan (1876-1934), an Austrian engineer, realized that changing the pitch of the blades could make a turbine with a greater range of applicability. In 1913, Kaplan designed a variable pitch propeller turbine, the Kaplan turbine. Since that time, the operating head of the Kaplan turbine has been increased, and smaller Kaplan turbines have been used for heads as high as 65 m. The Kaplan turbine runner is hydraulically similar to the propeller turbine runner except that the hub is larger to accommodate the mechanism for blade angle shifting. The servomotor to accomplish this is located in the hub in some designs (A. Furukawa et. al, 2010) (T.K. Ghosh et. al, 2011). References (Parker, 1996) (P. Singh et. al, 2009) (S. Derakhshan et. al, 2012) presented an axial hydro turbine with low heads micro potential flow ranged from 1 m to 5 m.

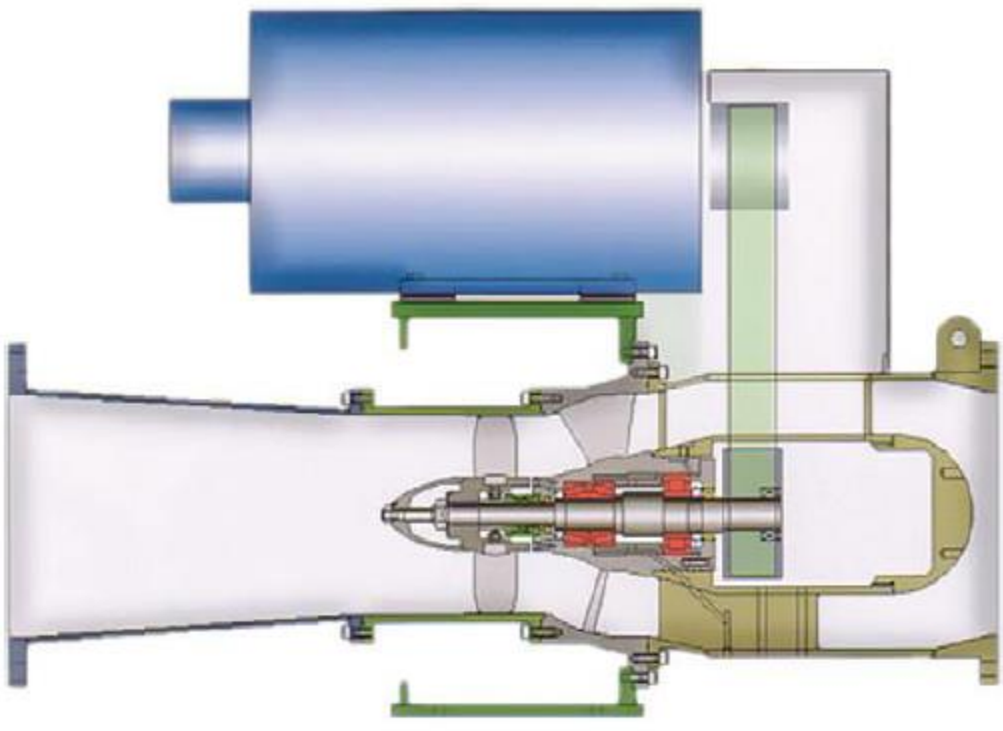

Figure 2.9 Axial Flow Turbines "Propeller and Kaplan Turbines"

2.3.3 Pump as Turbine (PAT)

In pumping mode, the fluid enters at suction side of pump at low pressure and gets energized by the impeller, which is rotated by some external means, and leaves the casing at high pressure. Whereas in case of PAT in (Figure 2.11), the pump rotates in reverse direction, water enters in the pump at very high pressure from the casing and moves through the impeller blades and releases its pressure and kinetic energy to the impeller shaft as mechanical energy and fluid comes out from the eye of pump at low pressure (K.H. Motwani et. al, 2013) (T. Agarwal et. al, 2012).

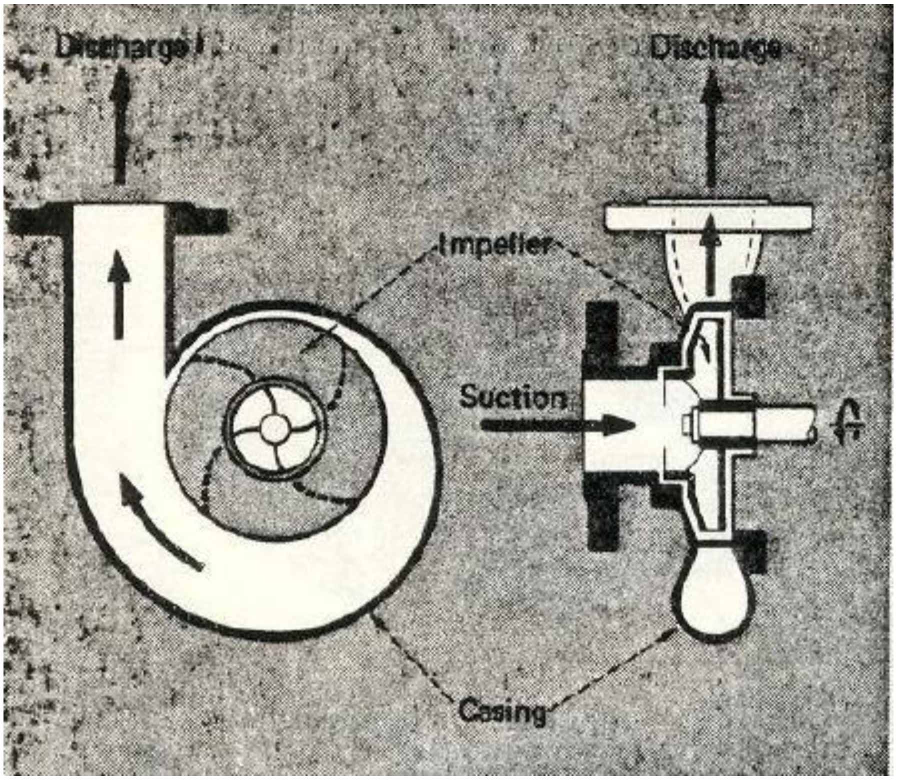

Figure 2.10 :Pump as Turbine (PAT)

The research on using PAT started around 1930 and the main challenge in PAT usage was the selection of a proper PAT for a small and Micro hydro-site (S. Derakhshan et. al, 2008). The main problem of using a pump as turbine is still the difficulty of predicting accurately the turbine performance, pump manufacturers do not normally provide the characteristic curves of their pumps working as turbines (S. Derakhshan et. al, 2008). Hence references (K.H. Motwani et. al, 2013) (S. Derakhshan et. al, 2008) (J.D. Burton et. al, 1992) (Williams, The Turbine Performance of Centrifugal Pumps: A Comparison of Prediction Methods, 1994) (Williams, Pumps as Turbines for Low Cost Micro Hydro Power, 1996) presented methods to predict the performance of PAT which based on the data for pump performance at best efficiency a wide range of results.

2.4 Other Reaction Turbines

2.4.1Barker's Mill

Barker's mill, which is shown diagrammatically in (Figure 2.12), was the first hydraulic reaction turbine and was invented in about 1740 and this machine was further refined by Pupil in 1775 and Whitelaw in 1839. One refinement of this turbine is to feed the water into the underside of the rotor. By feeding water into the turbine from underneath, the upward action of the static pressure of the entering feed water may be used to counteract the downward gravitational force on the moving parts thereby reducing the thrust load on the bearings supporting the moving parts (Abhijit Date et. al, 2013).

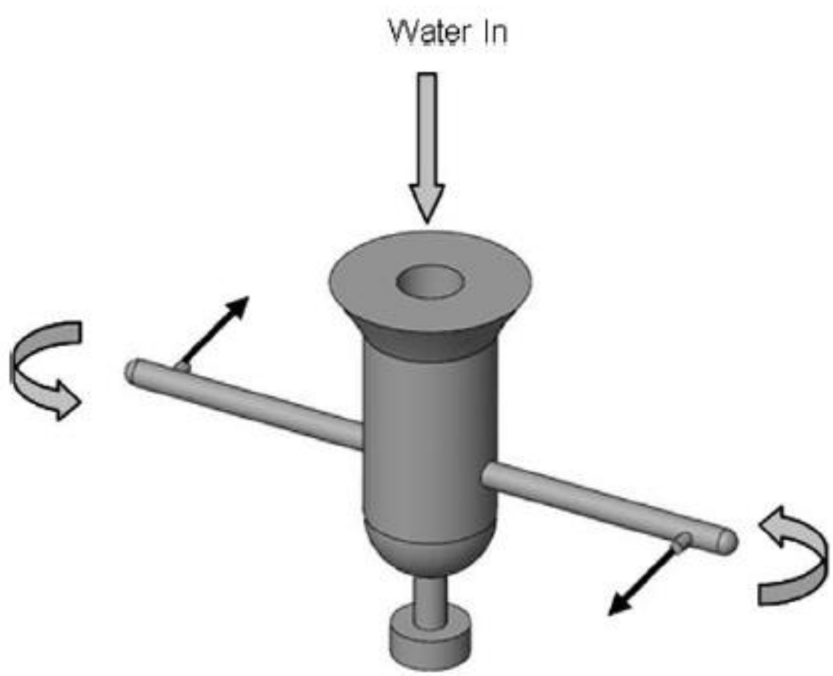

Figure 2.11: Barker's Mill

2.4.2 Split Pipe Turbine

The idea of split pipe reaction turbine is influenced by the ''Savonius wind rotor''. The split pipe reaction turbine as shown in (Figure 2.13) is manufactured by cutting a plastic pipe into two halves and then off-set the centers and joints the top and bottom plates (A. Date et. al, 2009). Reference (A. Date et. al, 2009) (N.J. Lee et. al, 2012) presented the performance characteristics of a simple Split reaction hydro turbine for power generation.

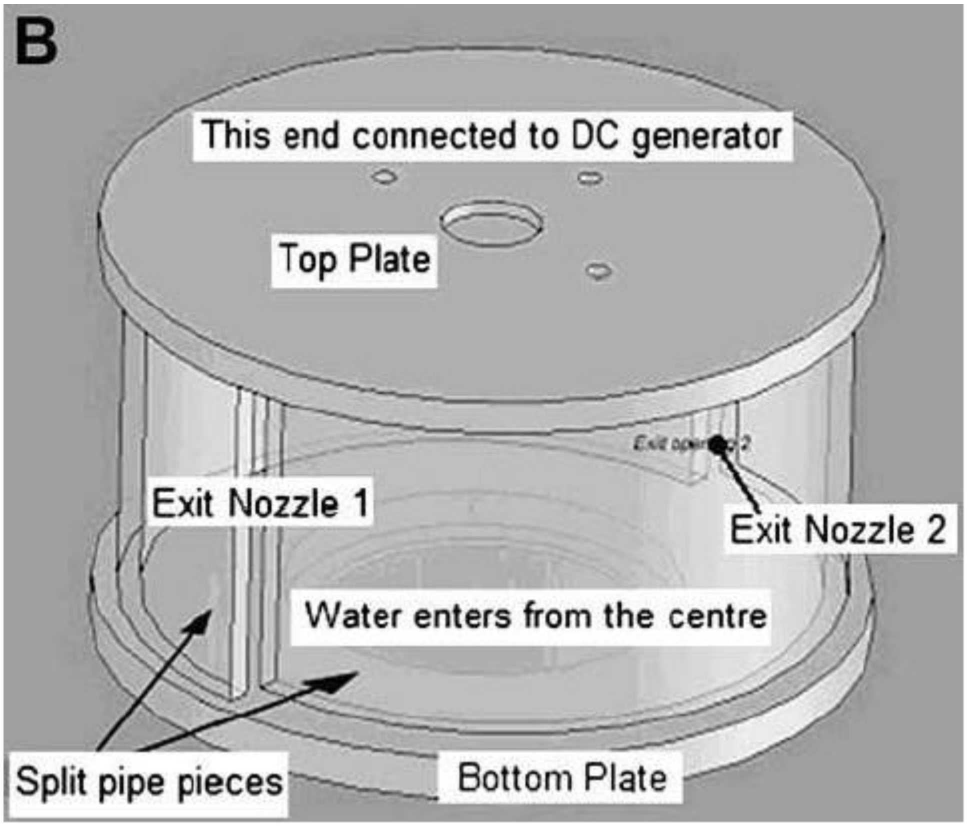

Figure 2.12 Split pipe reaction turbine

2.5 Other Micro Hydro Turbines Types

2.5.1 Counter-Rotating Tubular Turbine

Counter-rotating tubular type micro-turbine as shown in (Figure 2.14) contains front runner connected to the generator stator and the rear runner connected to the generator rotor. The performance of the system is investigated experimentally and numerically in reference (N.J. Lee et. al, 2012).

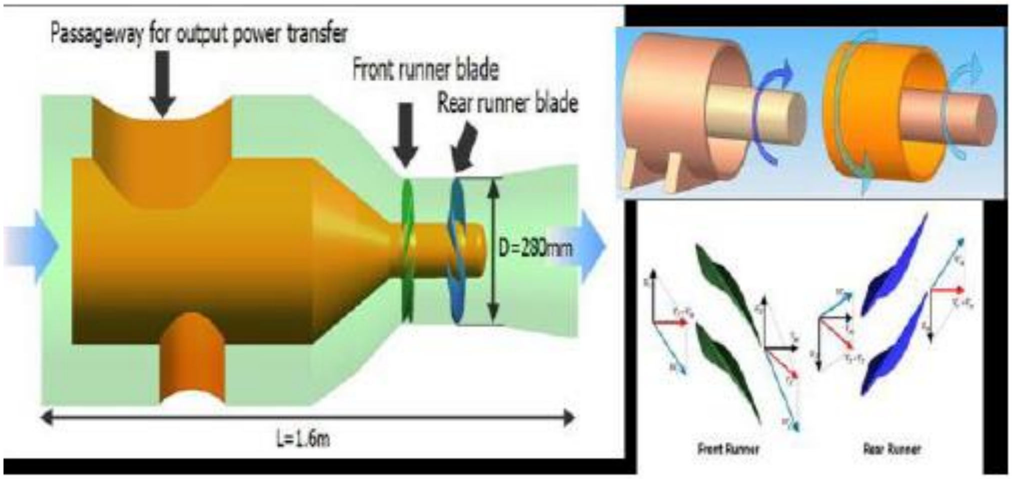

Figure 2.13 Counter-rotating tubular type micro-turbine

2.5.2 Screw Turbine

The highly efficient Archimedean screw has been “re-invented” to generate electricity all year round at 24 hours per day, whilst obtaining the natural flow of the river, in combination with its natural fish friendliness and a small fish trap it is one of the few systems that is able to maintain or even improve the wildlife in and around the river. The hydropower screw turns the principle of pumping around, maintaining the advantages and generating energy using the falling water to

drive the screw as shown in (Figure 2.15) (N.J. Lee et. al, 2012)

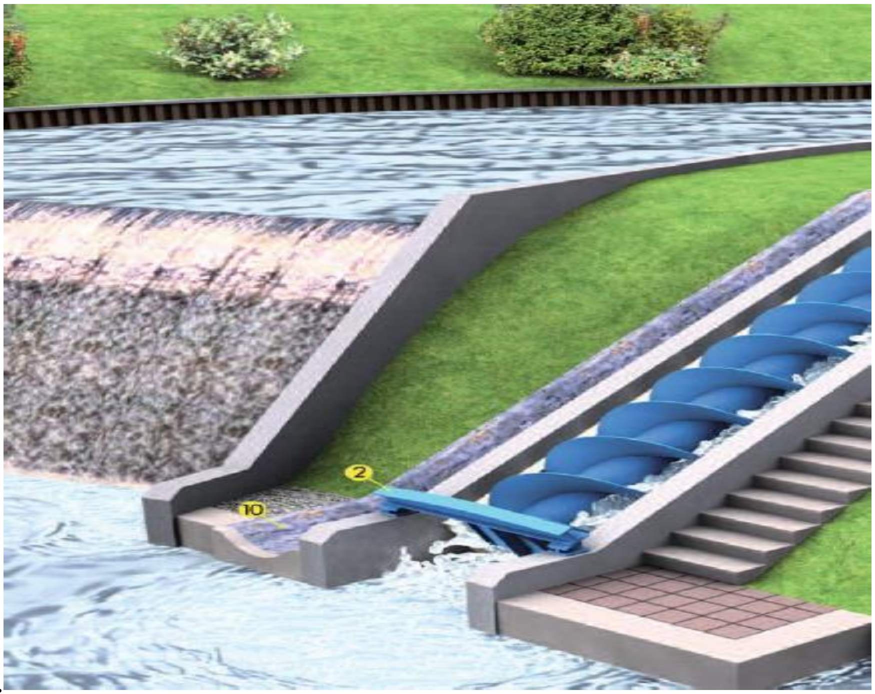

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Figure 2.14 Screw turbine

2.6 Vortex turbine

The water vortex turbine is a turbine used in hydroelectric power plant to generate electricity with low head and low flow rate. The water vortex turbine mainly comprises a runner and tank. On introducing a flow of water into the tank, the turbine generates electricity from the gravitation vortex that occurs while draining the water from the bottom of the tank.

It was first patented by Greek-Australian Lawyer & Inventor Paul Kouris in 1996 (Hydraulic Turbine Assembly, 1997), who was searching for a way to harness the power inherent in a vortex. Later, Austrian Inventor Franz Zotlöterer created a similar turbine while attempting to find a way to aerate water without an external power source. (Kimberley, 2007)

A vortex is generated in a circular basin with a tangential inlet and a central outlet. A vertical axis turbine is placed in the center of the vortex where the rotational speed is the highest. The turbine rotates with the swirling flow, thus generating mechanical energy which can be converted to electrical energy using a generator. The turbine's aeration of the water helps improve water conditions, while the reduced speeds of the turbine and the lack of cavitation ensure that most types of fish can pass through the turbine without danger, something which is much more difficult to achieve at normal hydro plants that require additional structures for the fish migration. (Hydraulic Turbine Assembly, 1997)

Figure 2.15 Vortex turbine

Vortex turbine typically has more advantage compare to other micro hydro turbine systems. Some of the advantages are stated below;

I. At the discharge of the vortex, contaminants are evenly distributed through the water, which also oxygenated, leading to improved efficiency of micro-organisms to decompose the contaminants; hence, cleaner water downstream.
II. The increased contact area between the water and air results in better cooling evaporation during the warm season, and a perimeter of ice insulate the water in cold season—all while the turbine continues gently turning out the watts.
III. The temperature self-regulation capacity of the water is further enhanced by the concentration of the densest water at the middle of the vortex. Since water is densest at 4^0 C tends to be cooled when it is pulled into the vortex and cooler water is warned by the mixing which the vortex causes. Biodiversity downstream is enhanced by the stabler temperatures. (Zotlotere, 2013)

In addition, the main properties of the vortex water turbine are as follows;

I. Increases the water vortex.

II. Maximizes the velocity of flow on the water surface area

III. Disseminates homogeneously contaminants in the water.

IV. Increases the contact surface of the disseminate for microorganism and water plants

V. Aerates the water naturally, because of high velocity of flow on the water surface area and the increased water surface are, to support the self-purification of water with microorganisms and water plants.

VI. Increases the heat of evaporation and so water can reduce the temperature itself at rising temperatures in the summer.

VII. Builds up a peripheral zone of ice in the winter to isolate the center of the vortex.

VIII. Concentrates dense water (water at 4^0 C) in the ring-shaped center to ensure the survival of microorganism as long as possible.

IX. Decelerates the flow of water, so it can be used as an active retention pond.

X. Concentrate rotation energy in the ring-shaped center and so it can be used for water power plant. (Zotlotere, 2013).

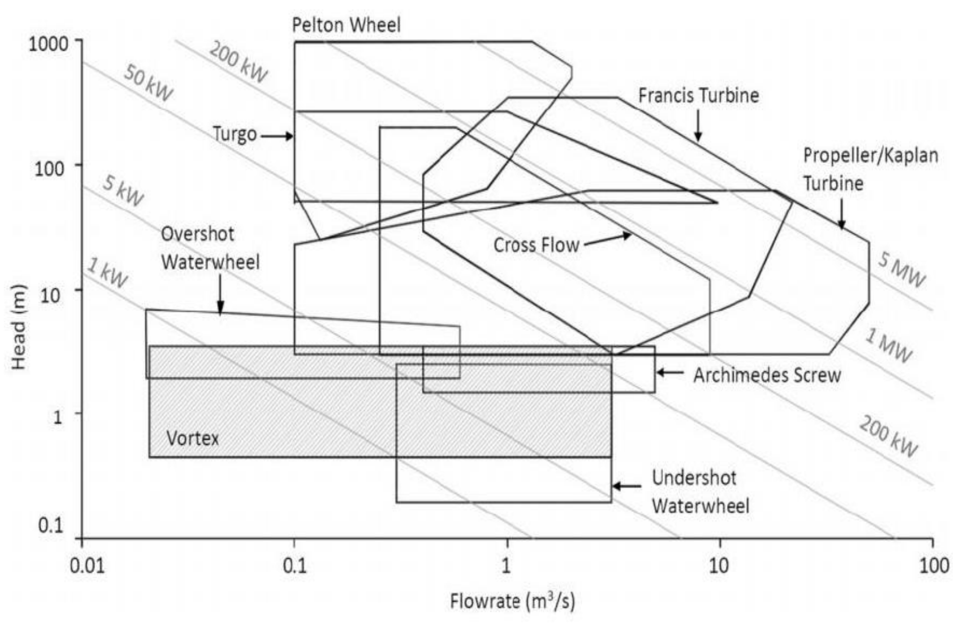

Figure 2. 16: Application Range of Hydraulic Turbines indicating range covered by Vortex Turbine (source ; (Timilsina, 2018)

Figure 2. 16 above shows The operating range of GWVHP is identified by (Timilsina, 2018) As seen it addresses the current gap of operation of low head hydropower systems. This makes them suitable on rivers across the Edo state, at so many locations. This has the possibility of removing or reducing the need for mega hydropower stations.

2.7 Generators

To convert from mechanical energy to electrical energy, the turbine is then connected to a generator. When mechanical energy is exerted and supplied to rotate the coil inside the generator at a uniform angular velocity ω, a magnetic field is created due to the permanent magnet inside the generator. This creates a sinusoidal electromotive force which is similar to a voltage. [59]

Based on Faraday's law;

$$E=Bv \tag{2. 11}$$

E = Electromotive force (volt)

B = Flux Density of a constant magnetic field (tesla, T)

v = Velocity (m/s)

When a resistance is applied, current is produced.

Ohms law indicates that:

$$V=IR \tag{2. 12}$$

Since electromotive force acts as a voltage, replacing the equation yields the new equation of

$$Bv=IR \text{ or } I=\frac{Bv}{R} \tag{2. 13}$$

This shows how the various energy conversions took place in a hydropower plant and how it is harnessed for the use of sustainable energy.

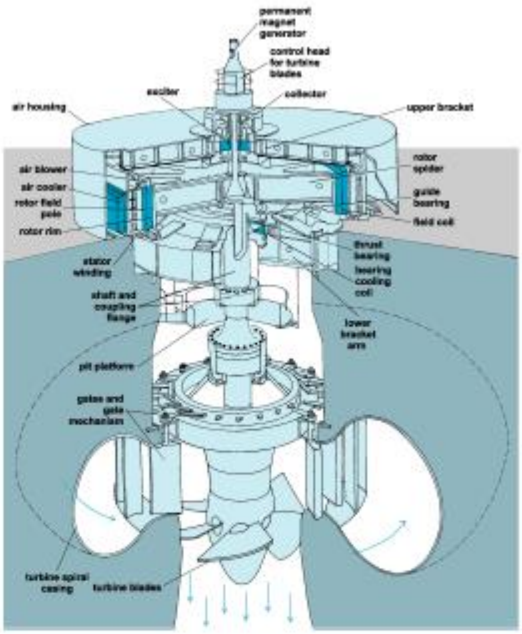

Figure 2.17 Generator of MHPT

2.8 Factors that affect Hydro energy systems

Study has shown that some of the major factors that enhance the efficiency of a Hydro Energy Systems for the purposes of generating electrical energy are:

1. Head difference

The most important consideration for hydro energy is the difference in head. The difference in head is also the amount of potential energy that is stored in a hydropower plant. The image below shows the definition of head, where head difference is the difference between the maximum height of water to the minimum height of water.

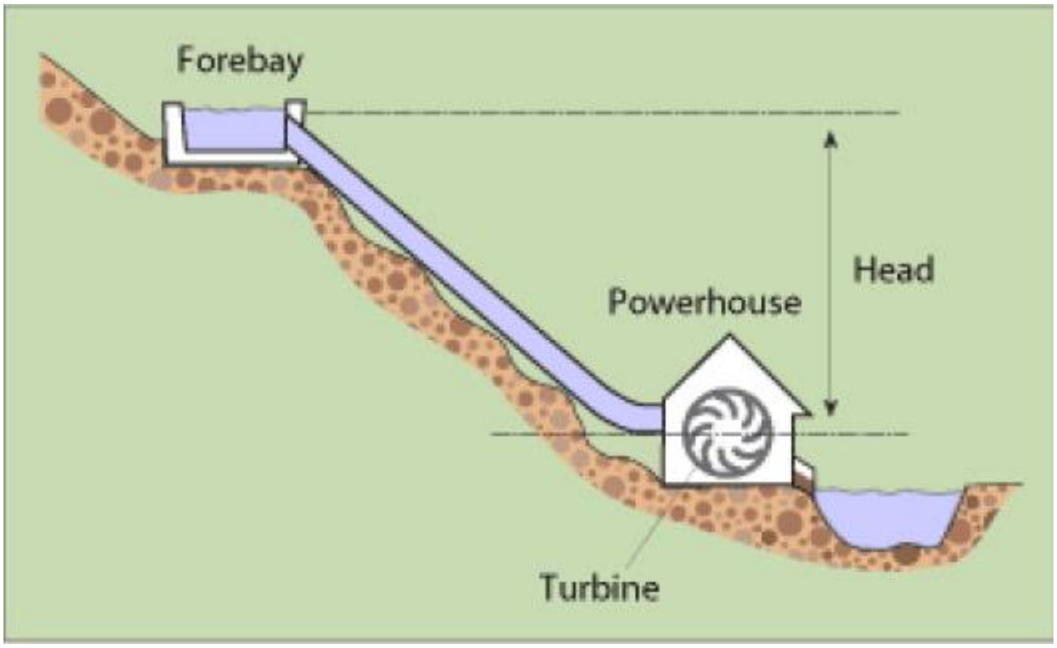

Figure 2.18 Image explaining head difference

In order to increase the head of a large power plant, a dam is built on the river. This will create a large reservoir which will increase the head hence directly increasing the amount of potential energy. The head needs to be kept high to maintain the high potential energy of the power plant. The correlation between head and power is defined in the theoretical power for a hydro energy system.

$$P=\rho g Q h \tag{2. 14}$$

2. Mechanical efficiency

The mechanical efficiency of the turbine affects the overall efficiency of the system. As hydropower turbines are much larger in size, the rotation of the turbine can cause high amount of stress on the bearings itself. The frictional force on the bearing will generate heat that will affect the turbine's performance. By using a cooling coil, bearing's efficiency can be improved.

3. Optimizing best linear velocity

As discussed earlier in the physics part of hydropower, the maximum amount of force generated on the buckets would be based on the relative velocity. By optimizing the best linear velocity that is supplied to the turbine, we can achieve good relative velocity. The optimization of the linear velocity can be done by controlling the flow of water with the opening and closing of the gate to the penstock. The best linear velocity for the turbine can be calculated. First, calculating the absolute velocity of the water using the equation expressed below.

$$V = C_d\sqrt{2gh} \qquad 2.15$$

Where C_d is the velocity coefficient and V is absolute velocity of the water. Next, the linear velocity of the turbine can be calculated.

$$u=V*m\cos\theta m\cos\theta-1 \qquad 2.16$$

By changing the θ, the ideal linear velocity can be obtained. This will help in designing the penstock for the hydropower system.

4. Head loss

Despite having a large potential energy due to high head, there is a strong possibility of head loss. The head loss can be categorized to a few types:-

I. Trash rack losses
II. Entrance losses
III. Stop log, gate slot and transition losses
IV. Friction losses in the pipes
V. Bend losses

While it is not possible to reduce the trash rack losses or the entrance losses, it is possible to reduce the friction and the bend losses. By designing a hydropower system with minimum amount of bends of the pipes, these losses can be minimized. A simulation can be done using engineering software such as ANSYS to provide a simulation on the amount of losses due to bend for a certain type of design. Frictional losses can be minimized by selecting the appropriate material for the pipes. Using PVC pipe can reduce friction, but they are not as solid as concrete. This depends on the specifications and requirements of the power plant. (Philip White et. al, 2009).

2.8 Review Of Related Literatures;

Christine Power. et. al. in their *Research Article* '**Performance and Flow Field of a Gravitation Vortex Type Water Turbine**' (Y. Nishi et. al, 2017) clarified the performance and flow field of a gravitation vortex type water turbine by conducting experiments and numerical analysis taking the free surface into consideration. They observed that the experimental and computational values of the torque, turbine output, turbine efficiency and effective head agree well with each other.

The Journal **'A Review on the Development of Gravitational Water Vortex Power Plant as Alternative Renewable Energy Resources'** by M. M. Rahman1. (M.M Rahman et.al, 2017) Et.al went through past researches to determine the gap in the vortex power plant technology and developed recommendations to accelerate the improvement of GWVPP. They observed that the conical shape basin has better performance than the cylindrical shape basin. They also observed that the inlet flow rate has significant effects on the efficiency.

Christine Power. E. in his Journal of clean energy **'A Parametric Experimental Investigation of the Operating Conditions of Gravitational Vortex Hydropower'** (C Power et. al, 2016)[did a parametric investigation of the operating conditions of GVHP such as inlet and outlet flow rates, blade number & blade sizes. They discovered that maximum efficiency occurs at the largest blade area and the maximum inflow rate,

In the Journal '**Power Generation with Simultaneous Aeration using a Gravity Vortex Turbine'** by **Anjali Mohanan M**[1], (A. Mohanan et. al, 2016) they proved the possibility of using a gravitational vortex turbine for power generation from drainage water. At the end of the journal, it was discovered that the turbine can generate power, aerate & segregate impurities which are added advantages to the turbine.

In a project '**Experimental and Numerical Analysis of Three-Dimensional Free-Surface Turbulent Vortex Flows with Strong Circulation',** (Mulligan, 2015) presented by Sean

Mulligan, an experimental and numerical analysis as well as analytical investigations was conducted on a Strong free-surface vortex flows. After his research, he confirmed that the tangential velocity of the vortex flow is independent of the subsurface depth.

Ajay Kumar Jha et. al in their works '**Assessment of Gravitational water vortex hydropower plant in Nepal'** (A.K. Jha et. al) presented a feasibility study on the development of a 1KW pilot system in Nepal. It was discovered that using locally sourced materials was more economical.

O.B Yaakob et. al in their work '**A Review on Micro Hydro Gravitational Vortex Power and Turbine Systems'** (O.B Yaakob et. al, 2014) focused free surface vortex (FSV) and the turbine systems used in micro hydropower and it was discovered that the FSV is a cornerstone of the gravitational water vortex power plant.

Sujate Wanchat et. al in their work **'Preliminary Design of a Vortex Pool for Electrical Generation'** (S. Wanchat et. al, 2011) in the Journal of computational and theoretical Nanoscience aimed at analyzing and designing a basin structure with the ability to form a gravitational vortex stream with low head ranging from 0.7m to 3m.

Piyawat Sritram et. al in their **'Comparative Study of small hydropower turbine efficiency at low head water'** (P. Sritram et. al, 2017) aimed at comparing 'water free vortex turbine' and 'the small under shot water wheel'. Considering the torque and energy as viable parameters. Results showed that while the torque produced was lesser than the former. Thus the water free vortex turbine was found to be more suitable than the small under shot water wheel at a height less than 1m.

Abdul Samad Sale in his work on '**Blade Optimization of Water Vortex Turbine'** (Samad, 2016) investigated the parameters that result in the formation and strengthening of the vortex and an efficient generation of energy using a strong artificial air cone vortex. In their analysis, it was found out the reduction of flow rate is different basin parameters led to increase in efficiency. Blade profiles were also analyzed and it was concluded that the cross flow blades produced the highest efficiency in the plant than other blade profiles for same discharge and head conditions.

According to Wanchat et. AL , They performed an experimental research on the vortex turbine. Their research parameter was the outer diameter which they varied and they discovered that the maximum efficiency was 30% and the outer diameter ranges from 0.20m and 0.35m. (Wanchat et. al, 2012)

According to Christine et. Al , They carried out an experimental research on the vortex turbine nine of which they altered the inlet flow rate and they discovered the highest efficiency of the inlet flow rate. (C. Power et. al, 2016)

Sagar et. Al carried out a simulation research method on a vortex turbine and their research parameter was the basin's structure and they discovered that a cylindrical basin with inlet guide has the best flow rate.

Sitram et. Al carried out an experimental research on the vortex turbine, of which different turbine materials was used and they found out that, Aluminum is more efficient than steel and has a maximum efficiency of 34.79%. (P. Sitram et. al, 2018)

Christine et. Al also carried out an experimental research on the vortex turbine by changing the configuration of the number of blades and sizes of the turbine blades. And they found out that the efficiency varied directly proportional to the number of blades and efficiency also varied directly proportional to the size of the turbine, with efficiency (E) =15.1% (S. Dhakal et. al, 2014)

Mulligan and Casserly did their research project on “Design and optimization of a water vortex hydro powerplant” carried out at the Institute of Technology, Sligo in Civil Engineering . This research concludes that optimum vortex strength occurs within the range of orifice diameter to tank diameter ratios(d/D) of 14– 18% for low and high head sites, respectively. Thus,for cylindrical basin, to maximize the power output, the range of orifice diameter to basin diameter ratios lies within14–18%. (S. Mulligan & J. Casserly, 2012)

Bajracharya and Chaulagai focused on developing innovative low head water turbine for free flowing streams suitable for micro-hydro power in Terai region of Nepal (K.H. Motwani et. al, 2013). In this study,water vortex was created by flowing water through an open channel to a cylindrical structure having a bottom whole outlet .Their search concluded that for a fixed discharge condition, the height of basin , diameter and bottom exit hole are fixed, i.e, the basin geometry depends on the discharge supplied .This study suggests that, in sufficient flow condition ,vortex minimum diameter is at bottom level and is always smaller than the exit hole.

Wanchat and Suntivarakorn studied the effect of basin structure information of water vortex stream (S. Wanchat & R. Suntivarakorn, 2015) (S. Wanchat et.al, 2013). Their study indicates the important parameters which can determine the water free vortex kinetic energy and vortex configuration and they include the height of water, the orifice diameter, condition sat the inlet and the basin configuration. It was found that a cylindrical tank with an orifice at the bottom center with the incoming flow guided by a plate is the most suitable configuration to create the kinetic energy water vortex. The power production varies along with head and flow. Therefore, for a given head and flow the different geometrical parameters that can be varied of conical basin for gravitational water vortex power plant are: (i)basin opening, (ii) basin diameter (iii) notch length (iv) Canal Height and (v) Cone Angle and among these parameters for a given basin diameter ,all other parameters has significant contribution for the change in velocity except notch angle. Although the objective of study with Panditetal is different with similar principle ,their study also suggests that the geometry of hydro-cyclones is very sensitive to its hydraulic and particle removal capability (H.P. Pandit et. al, 2009).

Zotlöterer has constructed a low-head power plant that makes use of the kinetic energy inherent in an artificially induced vortex. The water's vortex energy is collected by a slow moving, large-surface water wheel, making the power station transparent to fish - there are no large pressure differences built up, as happens in normal turbines. It can see at Fig 2.16. (Zotlotere, 2013). However, this study focuses on determining the flow characteristics of the river (ikpoba river to be precise), Designing of a vortex turbine using the data available from survey(of the ikpoba river), determining the Performance evaluation analysis of the vortex turbine i.e (theoretical/actual analysis) and getting the actual power of the plant.

CHAPTER THREE

METHODOLOGY

3.1 Description Of The Ikpoba River

Ikpoba River is a fourth order stream situated within the rain forest belt of Edo State, southern Nigeria. The River rises from the Ishan Plateau in the northern part and flowing in south westerly direction in a steeply incised valley and through sandy areas before passing through Benin City and joining the Ossiomo River. Edo State lies roughly between longitude 06o 04'E and 06o 43'E and latitude 05o44' N and 07o34' N. Edo State has a tropical climate characterized by two distinct seasons: the wet and dry seasons. The wet season occurs between April and October with a break in August, and an average rainfall ranging from 150 cm in the extreme north of the State to 250 cm in the south. The dry season lasts from November to April with a cold harmattan

Figure 3. 1: Satellite area view of Ikpoba river

spell between December and January. The temperature averages about 25 °C (77 °F) in the rainy season and about 28 °C (82 °F) in the dry season. The climate is humid tropical in the south and sub-humid in the north. Ikpoba River is highly disturbed while passing through Benin City due to the high population density and the dependence on the stream. Victor and Dickson (1985) reported that in the upper reaches of the stream, it flows through a dense rainforest where surface run-off and organic matter from the surrounding vegetation contribute to organic input. At the outskirt of the city, riparian settlements are thinly populated, so that disturbance due to human activities is low and localized The river is particularly important to the people of Benin City. One of the major dams in the Edo State was constructed across the river in Okhoro Community. The name of the dam is Okhoro Dam. The dam was built mainly for water supply and is used by the Edo State Urban Water Board to supply pipe-borne water to some parts of Benin Metropolis. Down stream riparian communities depend on the river for water used for various (E. Uyigue & M. Agho, 2006).

Figure 3.2 Photo of student at the site measuring flow characteristics

At the site as shown in the Figure 3.2 above, flow measurement and characteristics of the river was taken. Flotation method was used in determining the flow rate of the ikpoba river, the calculations are shown below.

3.2 MATERIALS USED IN THE DETERMINATION OF RIVER FLOW CHARACTERISTICS (FLOW RATE), USING THE FLOAT METHOD.

a. Float(Tennis ball).
b. Twine.
c. Measuring tape.
d. Stopwatch.
e. Deadweight.
f. Rope.
g. Pegs.
h. Mallet.

3.3 METHOD

Once a suitable site was discovered, the length of the river reach was measured and a section of its width was measured out using the pegs(for marking out the measured length), measuring tape and the twine(tied to the pegs). This process forms a sort of square and this is considered our test area. A dead weight was attached to the rope and dipped into different parts of the marked out section and the average of the different depths calculated to determine the depth of the river at the site. Multiplying the average depth by the measured out width gave the cross-sectional area at that site. The average of the area gotten from different sections of the site is multiplied by the length of the site to determine the volume of the section. The float which in this case was a tennis ball was placed at one end of the twine and then allowed to flow along with the river. The time taken for the ball to get to the other end of the twine was measured using a stopwatch. This is done a number of times and the average is calculated. The volume is divided by the average time to determine the flow rate. This procedure was repeated at three different sites and the average of the different flow rates was calculated in order to estimate the flow rate of the river.

SITE A

SECTION 1

Total width = (10 + 10 + 10 + 10)ft = 40ft

Total depth = (15.6 + 16.67 + 20 + 19.2)ft = 71.47ft

Average depth =$\frac{Total\ depth}{No\ of\ intervals}$ = $\frac{71.47}{4}$ft

Average depth = 17.87ft

Cross-sectional Area = Total width × Average depth

Cross-sectional Area(A_1) = (40 × 17.87)ft = 714.8ft^2

SECTION 2

Total width = (10 + 10 + 10 + 10)ft = 40ft

Total depth = (14.1 + 19.9 + 18 + 19.2) = 71.2ft

Average depth = $\frac{Total\ depth}{No\ of\ intervals}$ = $\frac{71.2}{4}$ft = 17.8ft

Cross-sectional Area(A_2) = Total width × Average depth = (40 × 17.8)ft = 712ft^2

Average cross-sectional Area = $\frac{A1 + A2}{2}$

$\frac{714.8+712}{2}$ = 713.4ft^2

Where the length of the river reach(L) = 36ft

Average travel time = $\frac{T1 + T2 + T3}{3}$

T = Time taken for float to cover measured distance = $T_1 + T_2 + T_3$

T_1 = 9secs

T_2 = 9.2secs

T_3 = 8.4secs

Average travel time(T_m) = $\frac{9+9.2+8.4}{3}$ = 8.87secs

Therefore from site A, calculated parameters are;

Average cross-sectional Area(A) = 713.4ft^2

Where the length of the river reach(L) = 36ft

Average travel time(T_m) = 8.87secs

Flow rate = Area × velocity = $\frac{A \times L}{\mathrm{Tm}}$

Flow rate = $\frac{713.4 \times 36}{8.87}$ = 2895.4ft^3/s

SITE B

SECTION 1

Total width = (10 + 10 + 10 + 10)ft = 40ft

Total depth = (16.2 + 16.4 + 19.8 + 19)ft = 71.4ft

Average depth =$\frac{Total\ depth}{No\ of\ intervals}$ = $\frac{71.4}{4}$ft

Average depth = 17.85ft

Cross-sectional Area = Total width × Average depth

Cross-sectional Area(A_1) = (40 × 17.85)ft = 714ft^2

SECTION 2

Total width = (10 + 10 + 10 + 10)ft = 40ft

Total depth = (18 + 20 + 18 + 19.3) = 75.3ft

Average depth = $\frac{Total\ depth}{No\ of\ intervals} = \frac{75.3}{4}$ft = 18.83ft

Cross-sectional Area(A_2) = Total width × Average depth = (40 × 18.83)ft = 753.2ft^2

Average cross-sectional Area = $\frac{A1 + A2}{2}$

$\frac{714+753.2}{2}$ = 733.6ft^2

Where the length of the river reach(L) = 36ft

Average travel time = $\frac{\mathrm{T1} + \mathrm{T2} + \mathrm{T3}}{3}$

T = Time taken for float to cover measured distance = $T_1 + T_2 + T_3$

T_1 = 9secs

T_2 = 9secs

T_3 = 9.5secs

Average travel time(T_m) = $\frac{9+9+9.5}{3}$ = 9.17secs

Therefore from site A, calculated parameters are;

Average cross-sectional Area(A) = 733.6ft^2

Where the length of the river reach(L) = 36ft

Average travel time(T_m) = 9.17secs

Flow rate = Area × velocity = $\frac{A \times L}{\mathrm{Tm}}$

Flow rate = $\frac{733.6 \times 36}{9.17}$ = 2880ft^3/s

SITE C

SECTION 1

Total width = (10 + 10 + 10 + 10)ft = 40ft

Total depth = (19 + 20 + 19.9 + 19.2)ft = 78.1ft

Average depth =$\frac{Total\ depth}{No\ of\ intervals}$ = $\frac{78.1}{4}$ft

Average depth = 19.53ft

Cross-sectional Area = Total width × Average depth

Cross-sectional Area(A_1) = (40 × 19.53)ft = 781.2ft^2

SECTION 2

Total width = (10 + 10 + 10 + 10)ft = 40ft

Total depth = (19 + 20.4 + 21 + 19) = 79.4ft

Average depth = $\frac{Total\ depth}{No\ of\ intervals}$ = $\frac{79.4}{4}$ft = 19.85ft

Cross-sectional Area(A_2) = Total width × Average depth = (40 × 19.85)ft = 794ft^2

Average cross-sectional Area = $\frac{A1 + A2}{2}$

$\frac{781.2+794}{2}$ = 787.6ft^2

Where the length of the river reach(L) = 36ft

Average travel time = $\frac{\mathrm{T1 + T2 + T3}}{3}$

T = Time taken for float to cover measured distance = $T_1 + T_2 + T_3$

T_1 = 8.8secs

T_2 = 9.2secs

T_3 = 8secs

Average travel time(T_m) = $\frac{8.8+9.2+8}{3}$ = 8.67secs

Therefore from site A, calculated parameters are;

Average cross-sectional Area(A) = 787.6ft^2

Where the length of the river reach(L) = 36ft

Average travel time(T_m) = 8.67secs

Flow rate = Area × velocity = $\frac{A \times L}{\mathrm{Tm}}$

Flow rate = $\frac{787.6 \times 36}{8.67}$ = 3270.3ft^3/s

Therefore, Total estimated Flow rate of Ikpogba River = $\frac{flow\ rate\ site\ A +\ flow\ rate\ site\ B + flow\ rate\ site\ C}{3}$

Total estimated Flow rate of Ikpogba River = $\frac{2895.4+2880+3270.3}{3}$ft^3/s = 3015.23ft^3/s,

Therefore total estimated Flow rate of Ikpogba River = 85.375m^3/s

3.3 DESIGN MATRIX FOR THE SELECTION OF SUITABLE MICRO HYDRO TURBINE

The design matrix for selection of micro hydro turbine was done considering the following types of MHT;

- Francis turbine
- Propeller and Kaplan turbine
- Pump as turbine
- Barker's mill
- Screw Turbine
- Vortex water turbine

In creating the matrix, the above MHT types was evaluated with the following factors and grading factors were used;

FACTORS	**WEIGHT**
EASE OF MANUFACTURE	0.3
ECO-FRIENDLY	0.2
COST	0.15
MAINTENANCE	0.1
DURABILITY	0.095
POWER	0.08

RECYCLABILITY	0.075

Table3. 1 :design factor and weight table

TYPES OF MHT	EM 0.3	EC 0.2	C 0.15	M 0.1	D 0.095	P 0.08	R 0.075	TOTAL
FRANCIS TURBINE	4 / 1.2	3 / 0.6	9 / 1.35	4 / 0.4	9 / 0.85	2 / 0.16	2 / 0.15	4.715
VORTEX WATER TURBINE	7 / 2.1	8 / 1.6	6 / 0.9	8 / 0.8	9 / 0.85	9 / 0.72	7 / 0.53	7.5
PUMP AS TURBINE	5 / 1.5	8 / 1.6	6 / 0.9	7 / 0.7	8 / 0.76	8 / 0.64	6 / 0.45	6.55
BARKER'S MILL	6 / 1.8	4 / 0.8	4 / 0.6	7 / 0.7	8 / 0.76	5 / 0.4	2 / 0.15	5.21
PROPELLER AND KAPLAN TURBINE	5 / 1.5	2 / 0.4	7 / 1.05	4 / 0.4	4 / 0.38	8 / 0.64	2 / 0.15	4.52
SCREW TURBINE	6	5	8	2	9	3	4	5.595

	1.8	1.0	1.2	0.2	0.855	0.24	0.3	

Table3. 2 : design matrix for MHVT

From the above design matrix table the Vortex water turbine has the highest total value and therefore it is most suitable for installation on rural areas rivers in Edo state.

3.3 MODEL DESCRIPTION

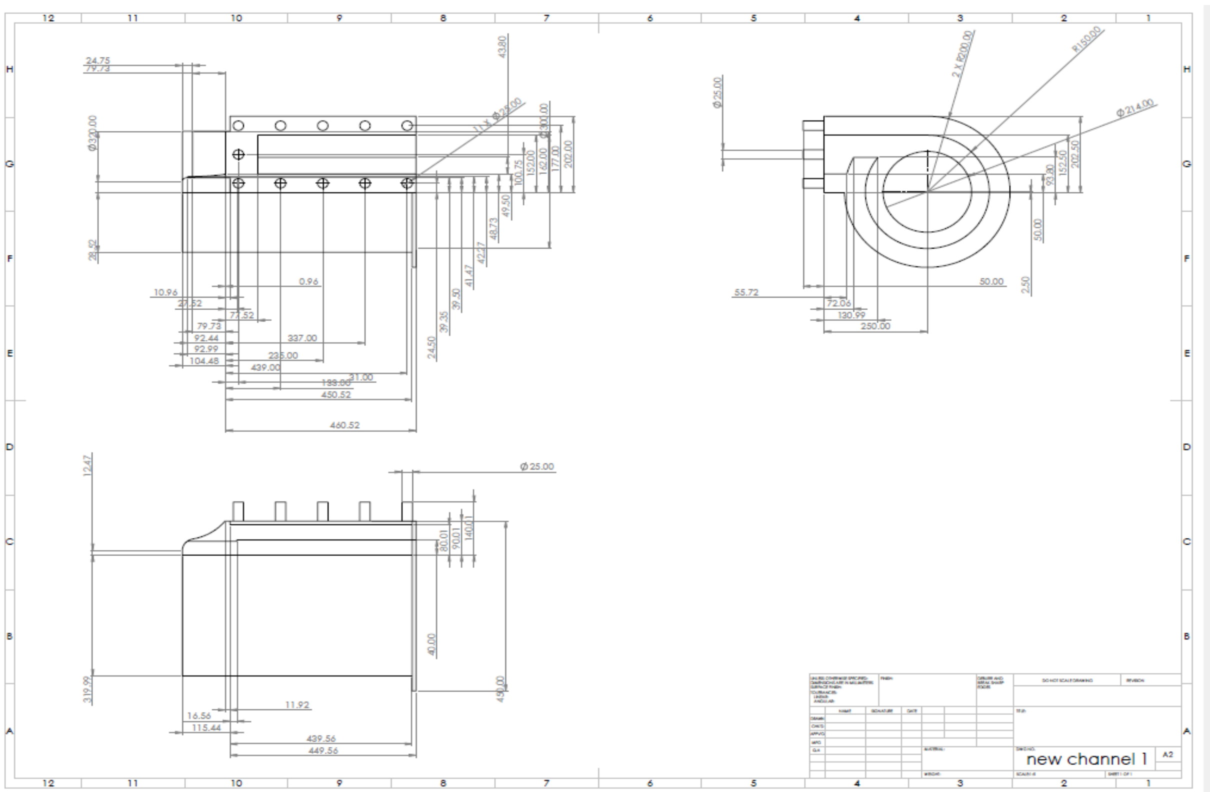

Figure 3. 3:Orthographic drawing of the open flow channel

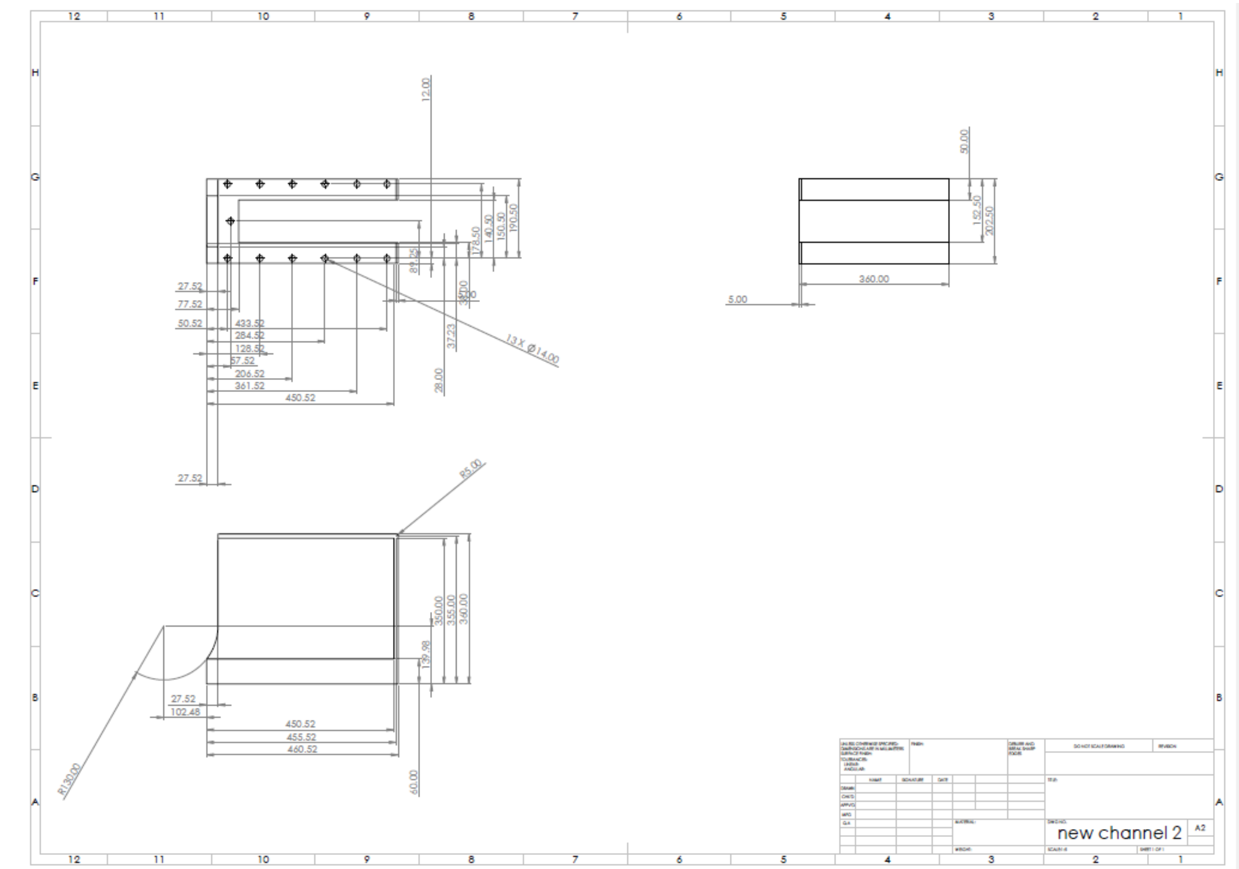

Figure 3. 4: Orthographic drawing of the vortex turbine base

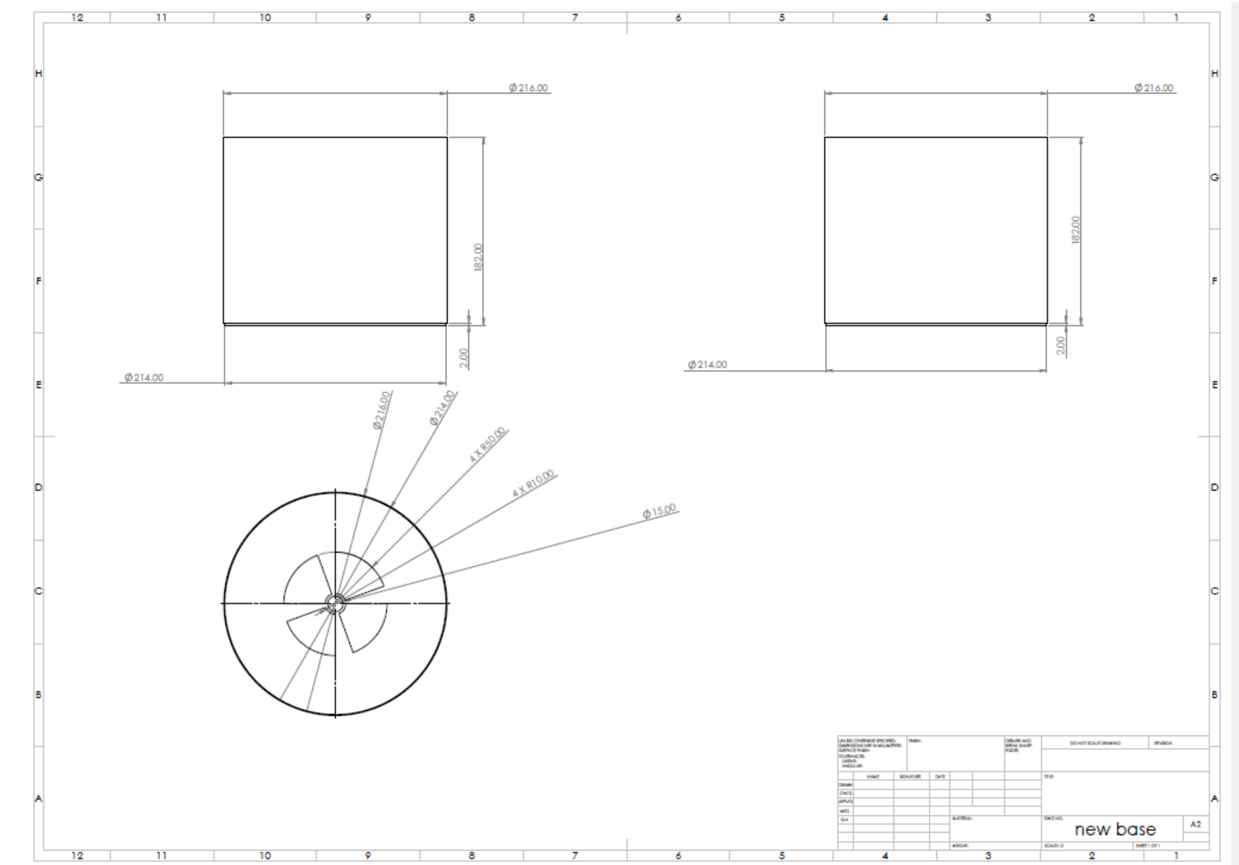

Figure 3. 5: Orthographic drawing of the turbine section base

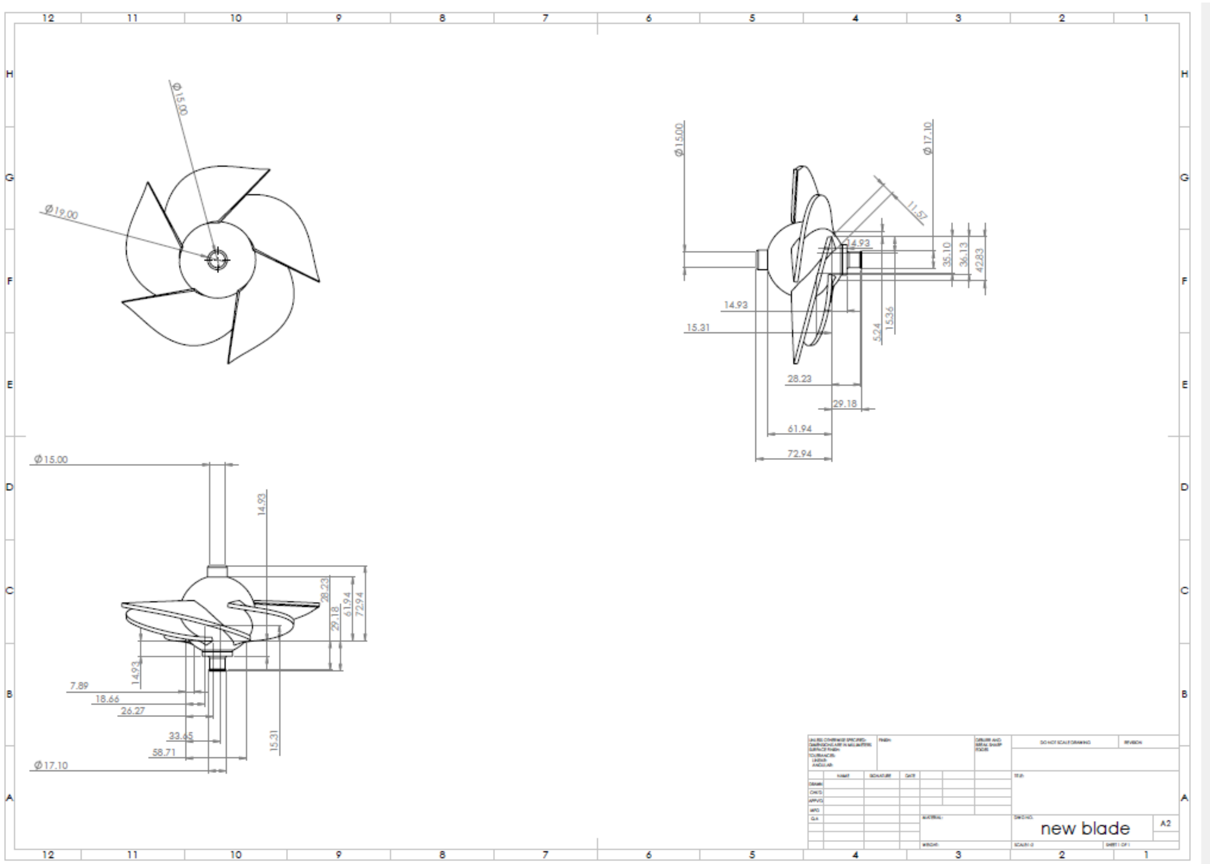

Figure 3. 6: Orthographic drawing of the vortex turbine (runner)

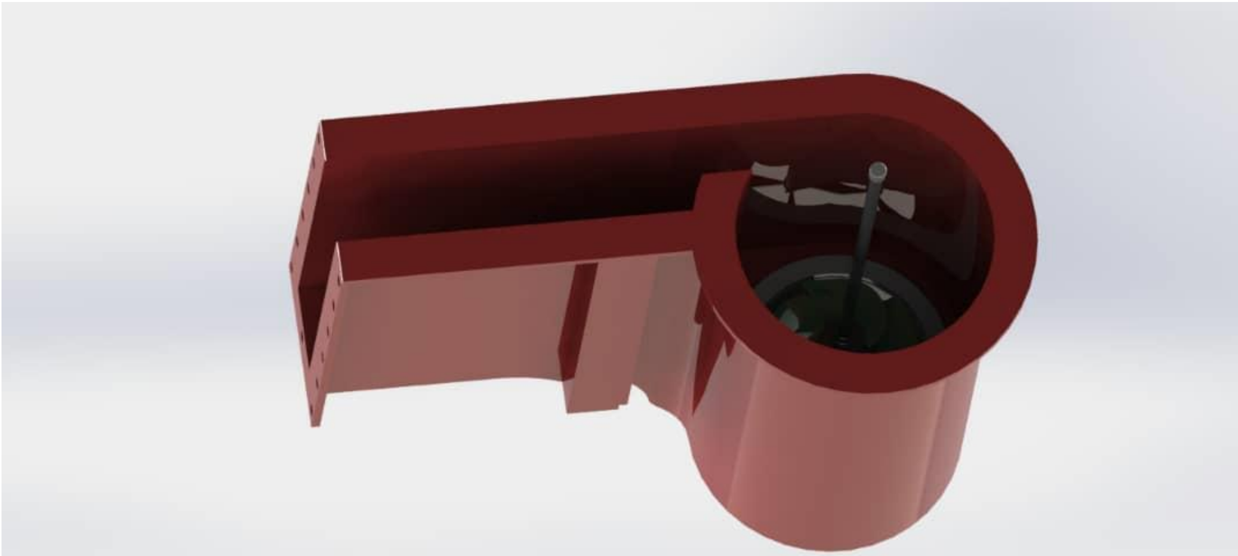

Figure 3. 7: 3D pictorial view of the flow channel

Figure 3. 8 : Pictorial 3D view of vortex turbine blade

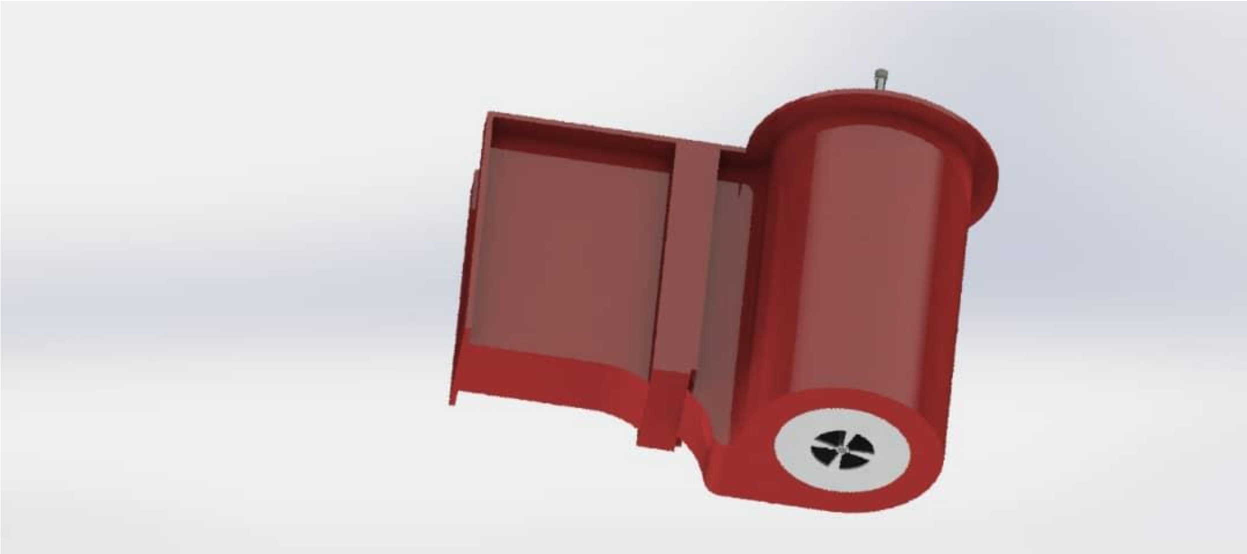

Figure 3. 9 : full right view of 3D model of the flow channel

The drawings above was design using solid works CAD software.

3.4 DETAILED DESIGN

The following components and their specifications will be highlighted. They include;

i. Vortex turbine blade (runner)
ii. Flow channel
iii. Bearing
iv. Shaft
v. Centrifugal pump

1. Vortex turbine blade;

Turbine blade is one of the most vital components for GWVPP. It is positioned at the center, aligned with the central outlet of the basin. The turbine is forced by the water power that come from the water vortex.

In the design of vortex turbine blade, some valid assumptions were made for the design of the model turbine. They are listed below:

1. Head and pressure losses are negligible.
2. The velocity with which the water strikes the runner is uniform along the length of the turbine.
3. The flow in the water vortex is inviscid and irrotational.

Let β_1 = 15°, β_2 = 19°, ID = 15mm, OD = 17mm for initial design. The head (H) was measured to be 0.3m while the flow rate was calculated was Q= 8.631m^3/s (of test rig used for experiment). Turbine depth from the upper surface of vortex was measured to be h = 0.3 m. At this depth, the radius of vortex was calculated to be r =12 mm by substituting in the parabolic trend line.

Turbine speed for an impulse type turbine is given by (Harvey A, 1993)

$$Nt = 39 \times \sqrt{H} \div \mathrm{OD}$$

Therefore, Nt = 191 rpm, which is the design speed.

Calculation of vortex velocity components

$$\mathrm{Vr} = 0$$

$$K = Q \div h = 0.01174\ \mathrm{m^2/s}$$

$$V\theta = K \div (2 * \pi * r) = 0.1558\ \mathrm{m/s}$$

Calculations at inlet

$$V1 = \sqrt{(2 * g * H)} = 3.91\ m/s$$

$$Vt = V1 + V\theta = 4.068\ m/s$$

$$Vw1 = \pi \times OD \times Nt \div 60 = 1.803\ m/s$$

$$Vf1 = Vt \times sin\ \beta1 = 1.121\ m/s$$

$$Vw1 = Vt \times cos\ \beta1 = 3.91\ m/s$$

$\alpha 1 = \tan^{-1}\left(Vf1 \div (Vw1 - U1)\right) = 28.02°$(30° chosen for fabrication convenience)

Calculations at outlet

$U2 = \pi \times ID \times Nt \div 60 = 1\, m/s$

$V2 = Vf1 = Vf2 = 1.12\, m/s$

$\alpha 2 = \tan^{-1}(Vf2 \div U2) = 48° \, (45° \, chosen\ for\ fabrication\ convenience)$

$Vw2 = Vt \times \cos\beta 2 = 0$

Calculation of theoretical power

$P_0 = þ \times Q \times g \times H = 66\, W$

Calculation of theoretical efficiency

$ŋ_h = (Vw1 \times U1) \div (g \times H) = 92.14\,\%$

Calculation of radius of curvature

$R = (OD^2 - ID^2) \div (2 \times OD \times \cos \beta 1) = 35\, mm$

Blade Design Summary :

S.No.	Parameters	Symbols	Design values
1	Blade inlet angle	β_1	15°
2	Blade outlet angle	β_2	19°
3	Radius of curvature	R	35 mm
4	Blade length	L	110 mm
5	Blade thickness	t	4mm
6	No. of blades	n	5

Table3. 3 : Blade design summary

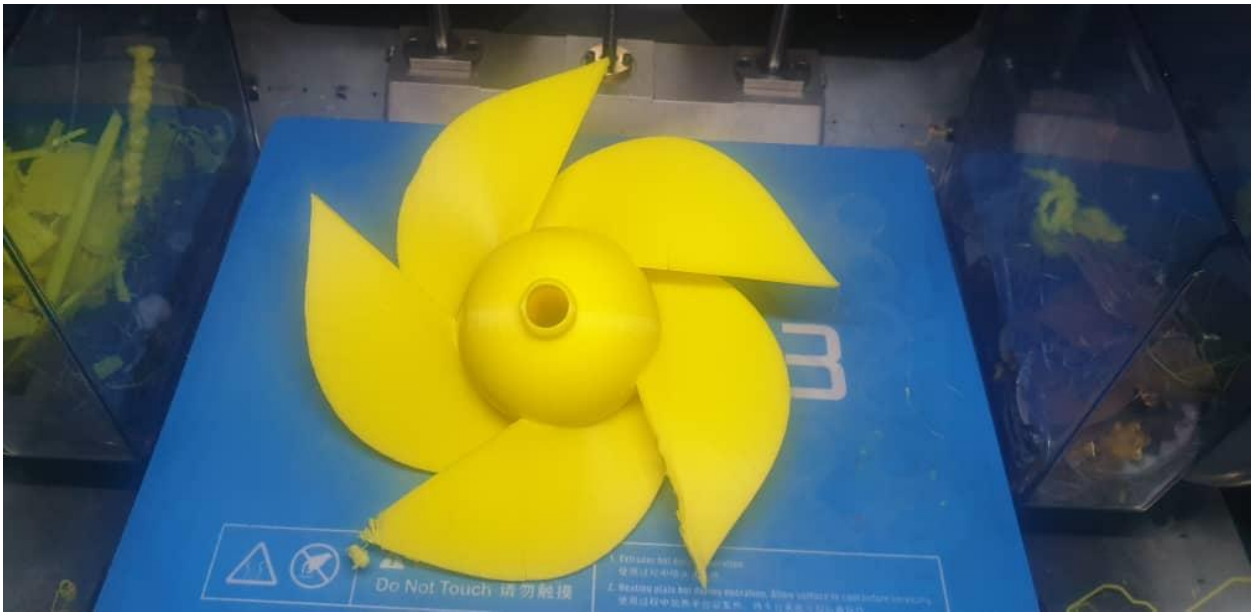

Figure 3. 10 : Image of the 3D printed blade.

2. Flow channel:

For GWVPP, the inlet flow rates are the water that is released into a channel connected to the basin. The channel is responsible to direct the water flow into the basin tangentially. It can be horizontal or slanted at desired angle. The channel width between two ends could be different or the same. One of the study that will be mentioned below also shows that the inlet of GWVPP could be in the form of pipe instead of channel (Power C & McNabola et. al, 3rd December 2019) (Kouris Centri Turbine, 4th December 2019). The inlet height has two meaning, first one deals with the height of water while another one indicate the height of channel from the bottom of the basin. The inlet and outlet parameters are shown in Figure 3.10 and Figure 3.11.

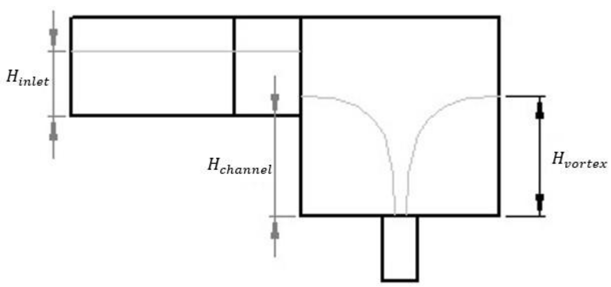

Figure 3. 11 :Gravitational Water Vortex Power Plant side view

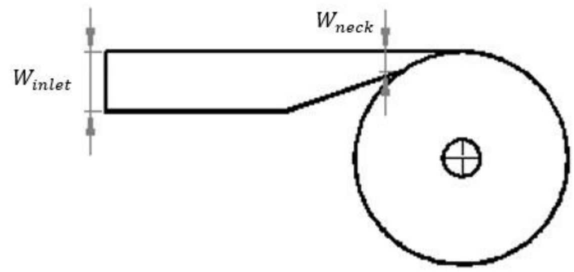

Figure 3. 12 : Gravitational Water Vortex Power Plant top view

Figure 3. 11 shows that the outlet was usually at the centre of the basin and its diameter has significant affect on vortex strength as well as efficiency of vortex turbine (S. Suntivarakorn R & Wanchat S et. al, 3rd December 2019) (Shabara H.M & Yaakob O.B et. al, 4th December 2019) (Shabara H.M & Yaakob O.B et. al, 3rd December 2019).

Wanchat et. al. (S. Suntivarakorn R & Wanchat S et. al, 3rd December 2019) studied the effects of outlet diameter varied from 0.10m to 0.40m on the efficiency of vortex turbine. The inlet velocity was set at 0.1m/s and the inlet channel was converged at the end which was connected to the basin. A five blades vertical axis turbine was used for electricity generation. It is found that the outlet diameter within the range from 0.20m to 0.35m has significant effect on power generation. The overall efficiency was reported as 30%. Shabara et. al. (Shabara H.M & Yaakob O.B et. al, 3rd December 2019) (Shabara H.M & Yaakob O.B et. al, 4th December 2019) conducted simulation and experimental studies. The GWVPP's $H_{channel}$ was zero. The simulation results showed that the outlet speed was inversely proportional to the outlet diameter. For the highest H_{inlet}, the outlet velocity was also maximum, which matched with the experimental results (Shabara H.M & Yaakob O.B et. al, 3rd December 2019) (Shabara H.M & Yaakob O.B et. al, 4th December 2019). The inlet flow rate has significant effects on efficiency. The efficiency of the vortex turbine is directly proportional to the inlet flow rate and the optimal $H_{channel}$ was one-third of the basin's height (Power C & McNabola et. al, 3rd December 2019). In this design, the specifications for the flow channel is given below:

Material – high carbon steel

Height of the channel inlet ($H_{channel}$): 0.4m

Height of the channel from buttom (H_{inlet}): 0.15m

Height of the channel relating to the vortex (H_{vortex}): 0.17m

Width of the vortex (W_{vortex}): 0.07m

Width of the channel ($W_{channel}$): 0.1m

Figure 3. 13 : Image of the fabricated flow channel.

3. Bearing:

The purpose of the bearing is to reduce rotational friction and support radial and axial loads.

Specifications:

Material – stainless steel

Inner diameter – 15mm

Outer diameter – 38mm

4. Shaft:

The shaft is a mechanical device that transmit the rotational motions of the runner to the generator. The diameter of the shaft was calculated using the equation below:

$$d = \left[\frac{16}{\pi\tau}\left\{\sqrt{(c_m \times M + \frac{\alpha F d}{8})^2 + (c_t \times T)^2}\right\}\right]^{\frac{1}{3}}$$

The diameter was calculated to be 0.0147 m i.e. 15 mm .

5. Centrifugal Pump:

A centrifugal pump is a mechanical device designed to move a fluid by means of the transfer of rotational energy from one or more driven rotors, called impellers. Fluid enters the rapidly rotating impeller along its axis and is cast out by centrifugal force along its circumference through the impeller's vane tips. The action of the impeller increases the fluid's velocity and pressure and also directs it towards the pump outlet. The pump casing is specially designed to constrict the fluid from the pump inlet, direct it into the impeller and then slow and control the fluid before discharge. The titling fumes equipment uses the centrifugal pump for its movement of fluids.

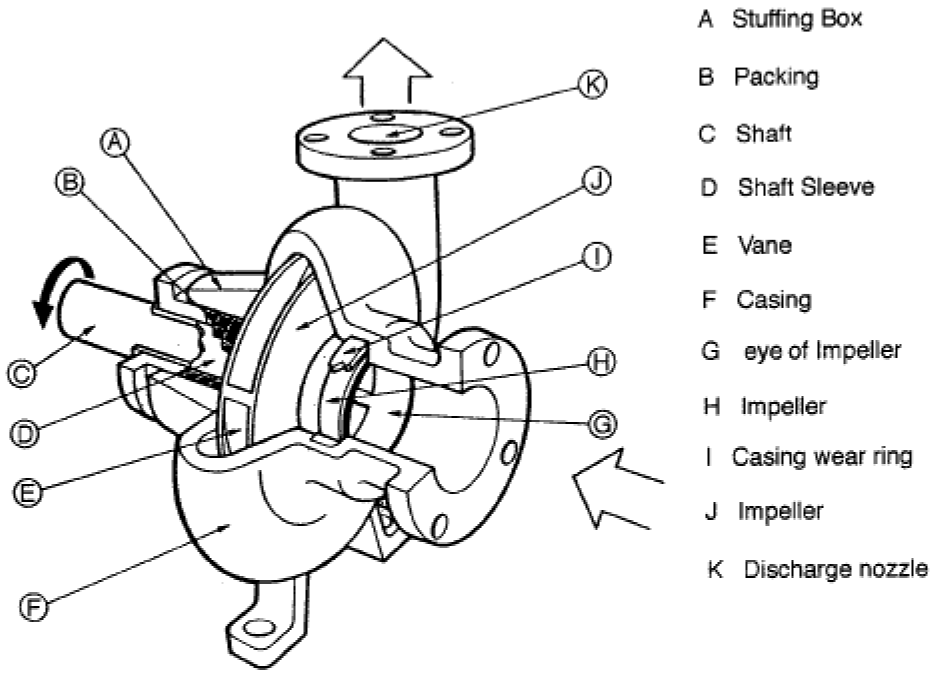

Figure 3. 14: detail view of the centrifugal pump

The head of a pump can be expressed in metric units as:

$$h = (p_2 - p_1) / (\rho\ g) + v_2^2 / (2\ g)$$

where

h = total head developed (m)

p_2 *= pressure at outlet* (N/m^2)

p_1 *= pressure at inlet* (N/m^2)

ρ *= density* (kg/m^3)

g = acceleration of gravity (9.81) m/s^2

v_2 *= velocity at the outlet (m/s)*

Head described in simple terms;

a pump's vertical discharge "pressure-head" is the vertical lift in height - usually measured in feet or m of water - at which a pump can no longer exert enough pressure to move water. At this point, the pump may be said to have reached its "shut-off" head pressure. In the flow curve chart for a pump the "shut-off head" is the point on the graph where the flow rate is zero

Pump Efficiency

Pump efficiency, η *(%)* is a measure of the efficiency with which the pump transfers useful work to the fluid.

$\eta = P_{out} / P_{in}$ *(2)*

where

η *= efficiency (%)*

P_{in} *= power input*

P_{out} *= power output*

EQUATIONS FOR POWER AND EFFICIENCY FOR MHPVT

The input and output powers and the turbine efficiency are calculated as follows:

Input Power, $P_{in} = \rho gQH$ (in watt) 3. 1

Where ρ = Water density (kg/m^3)

g = Gravitational constant (9.81m/s^2)

Q = Turbine flow rate (m^3/s)

H = Height (Head) of Vortex (m)

The power input is influenced by the height of the vortex and the water flow rate (C Power et. al, 2016).

Output Power, $P_{out} = T\omega$ **3. 2**

Where T = Fr 3.3

Where T = Torque

ω = Angular Velocity (rads/s)

F = Force (N)

r = Radius of the basin (m)

$$\text{Efficiency, } \eta = \frac{Output\ Power}{Input\ Power} \times 100 \qquad 3.4$$

$$\text{Efficiency, } \eta = \frac{\text{Pout}}{\text{Pin}} \times 100 \qquad 3.5$$

3.6 Fabrication of the system

1. Cutting
2. Welding
3. Assembling

3.7 Bill of material and cost evaluation

S/N	COMPONENT	QUATITY	UNIT COST(NAIRA)	TOTAL COST(NAIRA)
1	3d printed Vortex turbine blade	1	50,000	50,000
2	Alternator	1	20,000	20,000
3	Sheet metal plate	4	3000	12,000
4	Ball bearing	2	100	200
5	shaft	1	4000	4000
6	wire	2 yards	1000	1000

7	Bulb	2	200	200
8	Impeller	1	1000	5000
9	Gasket	2	800	1600
10	Electrodes	One-quarter pack	500	500
11	Shaft sleeve	1	1000	1000
12	Gum	2	200	400
13	Bolts and nut (15mm)	4	100	400
14	Vane	1	3000	3000
15	Fuse	1	2500	2500
16	Wire coil	1	6000	6000
TOTAL				107,800

Table3. 4 : Bill of materials

TOTAL COST

S/N	DESCRIPTION	AMOUNT (₦)
1	Materials	107,800
2	Labour/Production	50,300
3	Miscellaneous	5000
TOTAL		**163,100**

Table3. 5 : Total expenditure table

CHAPTER FOUR

RESULTS AND DISCUSSION

The results obtained from all experimental procedures are outlined in this chapter and all parameters and readings which contribute to the efficiency and power of the portable water turbine fabricated are analyzed.

4.1 TABULATION OF RESULTS OBTAINED

At 0.7m

N(rpm)	248	233	256	251
Q(L/s)	1.10	0.89	1.09	0.98
F(N)	4.5	3.7	4.3	3.9

Table 4. 1: Results gotten at 0.7m head

At 0.8m

N(rpm)	235	223	242	240
Q(L/s)	0.95	0.92	0.97	1.01
F(N)	3.2	2.9	3.3	3.1

Table 4. 2: Result gotten at 0.8m head

At 0.9m

N(rpm)	221	229	220	225
Q(L/s)	0.85	0.82	0.87	0.79
F(N)	2.8	2.3	2.9	2.5

Table 4. 3: Result gotten at 0.9m head

Head(m)	**N(rpm)**	**Discharge, Q(L/s)**	**Force(N)**
0.7	**247**	**1.02**	**4.1**
0.8	**235**	**0.96**	**3.2**
0.9	**223.75**	**0.83**	**2.6**

Table 4. 4 : Tabulated result gotten from varying the head.

4.2 ANALYTICAL EQUATIONS

Force exerted on runner by jet (F) = $weight\ x$ 9.8 (4.1)

Rated power= $F\ x\ N\ x\ R$ where, (4.2)

F=force exerted on the runner by the jet

N=Turbine Speed

Q= Discharge

Jet velocity $V_1 = C_v$ x $2gH^{1/2}$ (4.3)

Water power=wQH (4.4)

channel speed U = $\Pi DN/60$ (4.5)

$\eta_{mechanical}$ = Pout/Pin = shaft power/water power (4.6)

$\eta_{hydraulic} = (2(V_{w1}+V_{w2}) \times U) / V_1^2$ where, (4.7)

V_{w1}=whirl velocity at inlet to flow channel which equals the jet velocity

V_{w2}=whirl velocity at outlet of channel

Volumetric efficiency, η_v = volume of water actually imparting the runner, Q_a / total water supplied by the jet to the turbine

Volumetric efficiency $\eta_v = Q_a / Q$ (4.8)

Q_a = Area of Jet x Jet Speed (4.9)

$Q_a = (d)^2 /4 \times V_1$

4.5 CALCULATIONS

At 0.7mfeets

H=0.7m, N=247rpm, D= 0.24m

Nozzle discharge Q=0.00102m^3/s

Weight exerted on shaft= 40.2kg

Calculation for flow channel speed

channel speed U= $\pi DN/60$ = $\frac{\pi \text{ x } 0.24 \text{ x } 247}{60}$= $3.10 m/s$

Jet velocity

Jet velocity $V_1=C_v\sqrt{2gH}$ = $0.78\sqrt{2x9.81x6.71}$ = 8.95m/s

<u>Calculation for hydraulic efficiency</u>

Hydraulic efficiency, η_h

$V_1 = V_{w1}$ = 8.95m/s

$V_{r1} = V_1 - U$ = 8.95-3.10=5.85m/s

k= $V_{r2}/V_{r1}{}^2$

$V_{r2} = kV_{r1}$ = 0.85 x 5.85= 4.97m/s

$V_{w2} = V_{r2}\cos\emptyset - U$

V_{w2} = 4.97cos25 – 3.10 = 1.404m/s

$\eta_{hydraulic}= (2(V_{w1}+V_{w2}) \text{ x } U) / V_1^2$

η_h = (2(8.95+1.404)x3.1) / 8.95^2 = 80.14%

Volumetric efficiency

d=0.0127m, V_1 =8.95 m/s

$Q_a= \pi/4 \text{ x } (0.0127)^2 \text{ x } 8.95= 6.614 \text{ x } 10^{-4}$

Actual discharge, Q=0.00102m^3/s

η_v= Qa /Q

= $\frac{6.614 \text{ x } 10-4}{0.00102}$= 64.84%

Rated power

$P_w = F \times \omega \times R = 4.1 x 9.81 x 2\pi \times 247 x 0.12 = 124.84W$

Water power

$P_{in} = wQH = 9810 \times 0.00102 \times 6.71 = 369.95W$

Mechanical efficiency

$\eta_m = P_w/P_{in} = 124.84/369.95 = 0.3375 = 33.75\%$

Analysis is carried out at various head using this format and a table of value is obtained.

4.3 DATA CALCULATED FOR THE DESIGNED TURBINE

Head(m)	**Discharge(L/s)**	$\eta_{mechanical}$**(%)**	$\eta_{hydraulic}$**(%)**	$\eta_{volumetric}$**(%)**	**Power Output (W)**
0.7	1.02	64.84	80.14	33.75	124.84
0.8	0.96	64.77	79.17	26.41	97.44
0.9	0.83	61.09	78.2	21.40	79.17

Table 4. 5: data calculated from varying the head

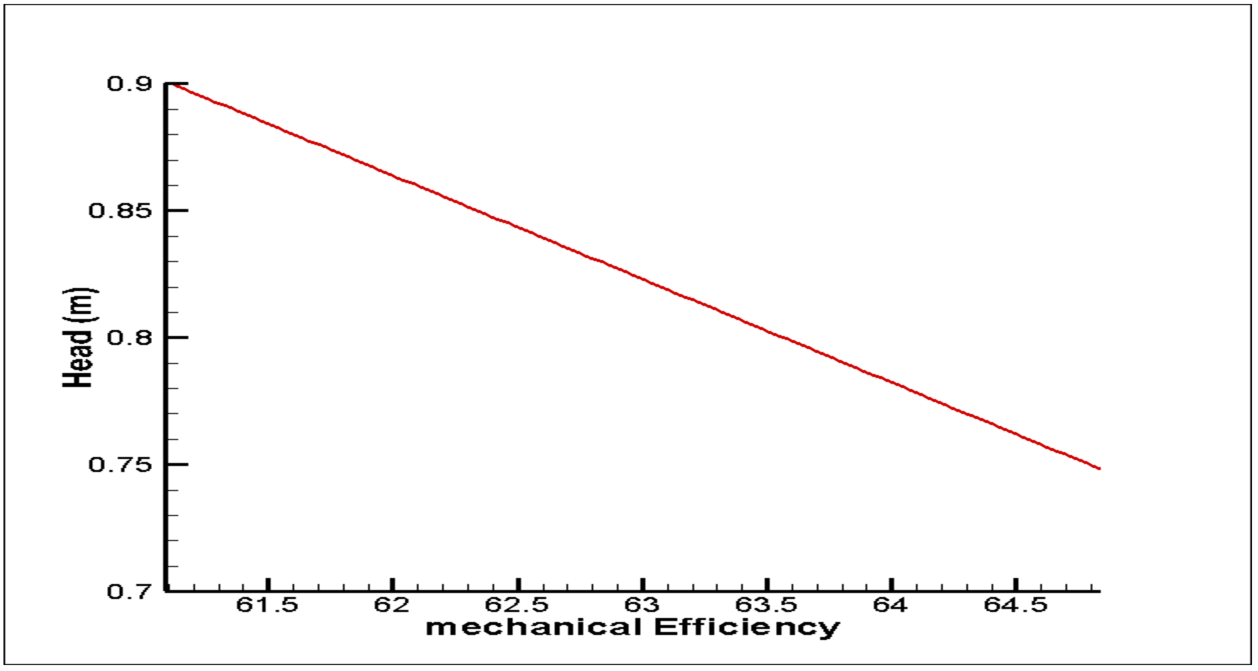

Figure 4. 1: plot of head against mechanical efficiency

As listed in table 4.5, three different heads (m) was tested ranging from 0.7m, 0.8m to 0.9m and as shown in the Figure 4.1 above , it is seen that decrease in head leads to increase in mechanical efficiency.

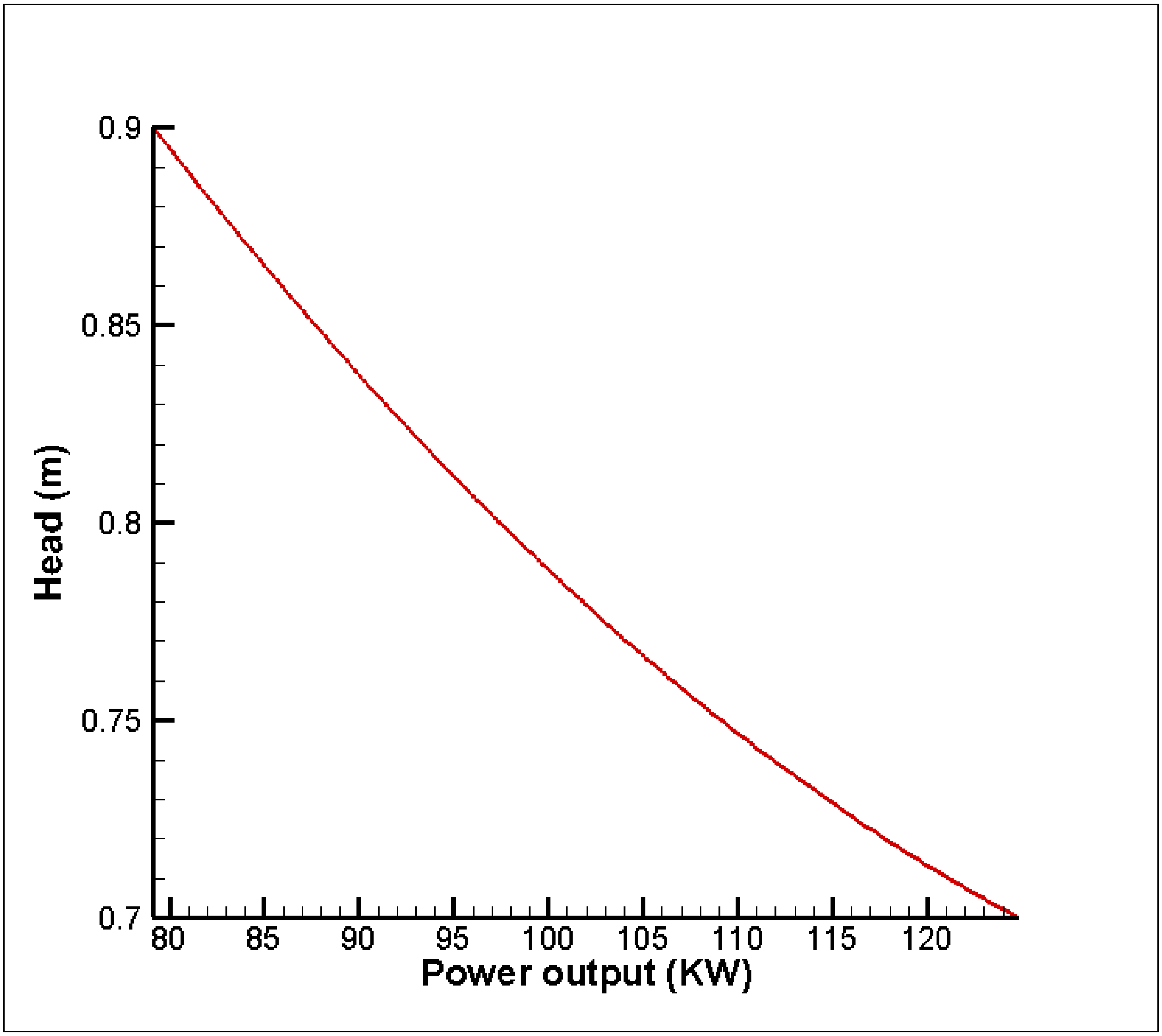

Figure 4. 2 : Plot of head against power output

A considerable variation of power output was observed in Figure 4.2 as the head(m) was decreased .The power output increased from 79.17W to 124.84W and the optimal power was found to have occurred at 0.7m.

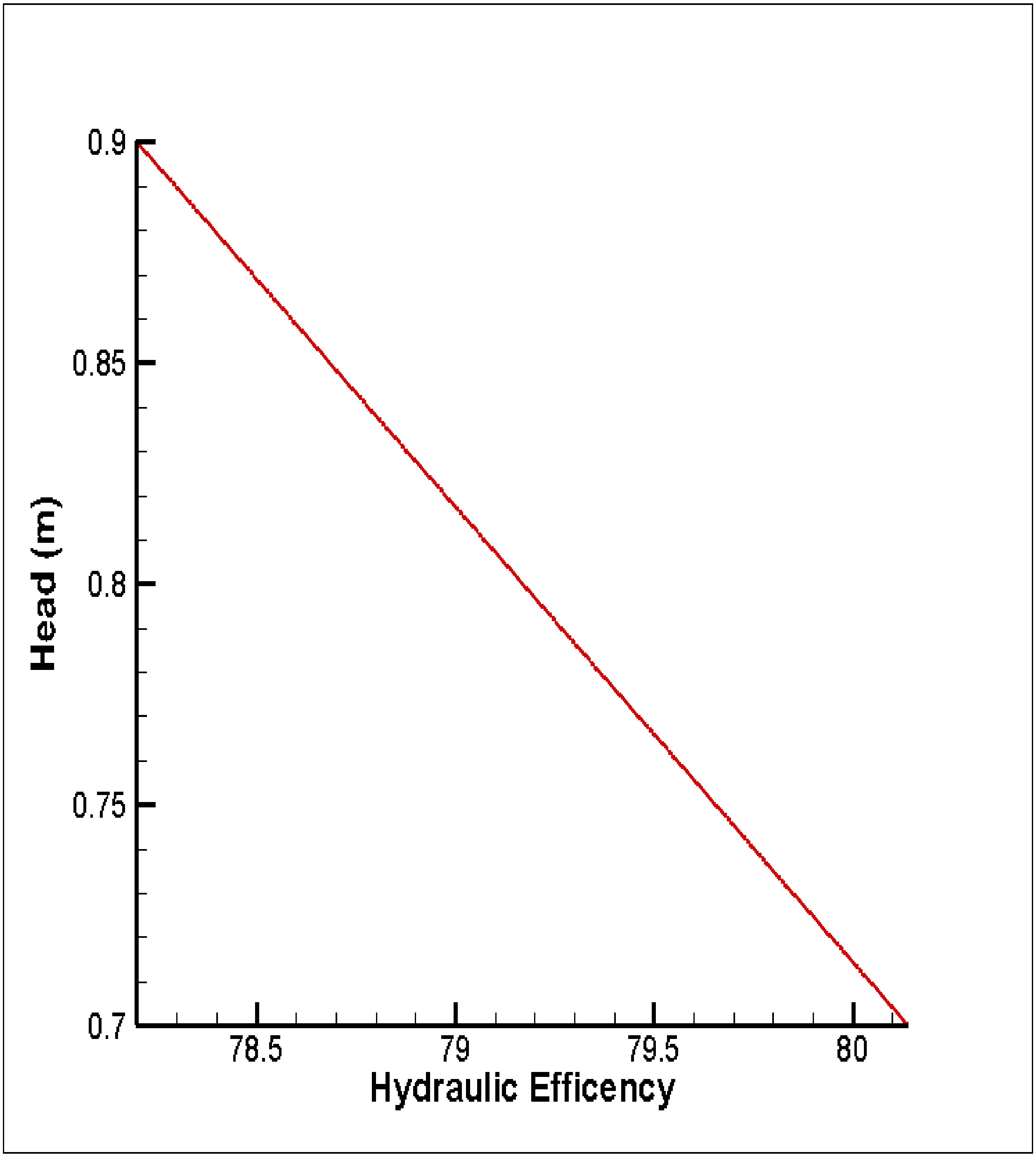

Figure 4. 3: Plot of head against hydraulic efficiency

The head of the flow channel was evaluated against hydraulic efficiency with experimental test (see Figure 4.3). As shown above, the hydraulic efficiency decreases as the head(m) increases.

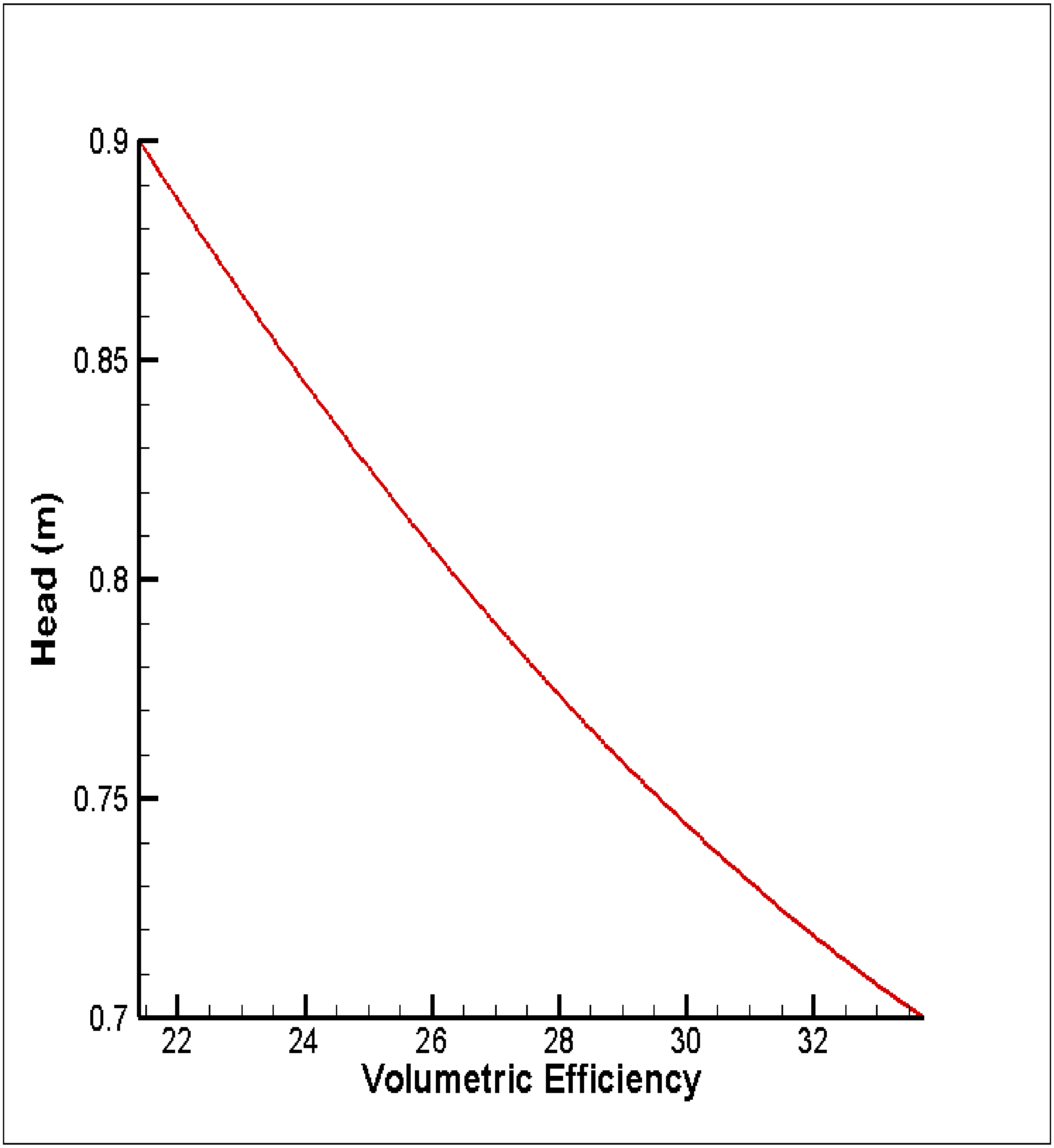

Figure 4. 4: Plot of head against volumetric efficiency

The above plot shows the relationship between head(m) and volumetric efficiency, various head(m) readings where taken for 0.7m, 0.8m and 0.9m as showed in table 4.5. It was observed that as the head(m) increases, the volumetric efficiency is reduced.

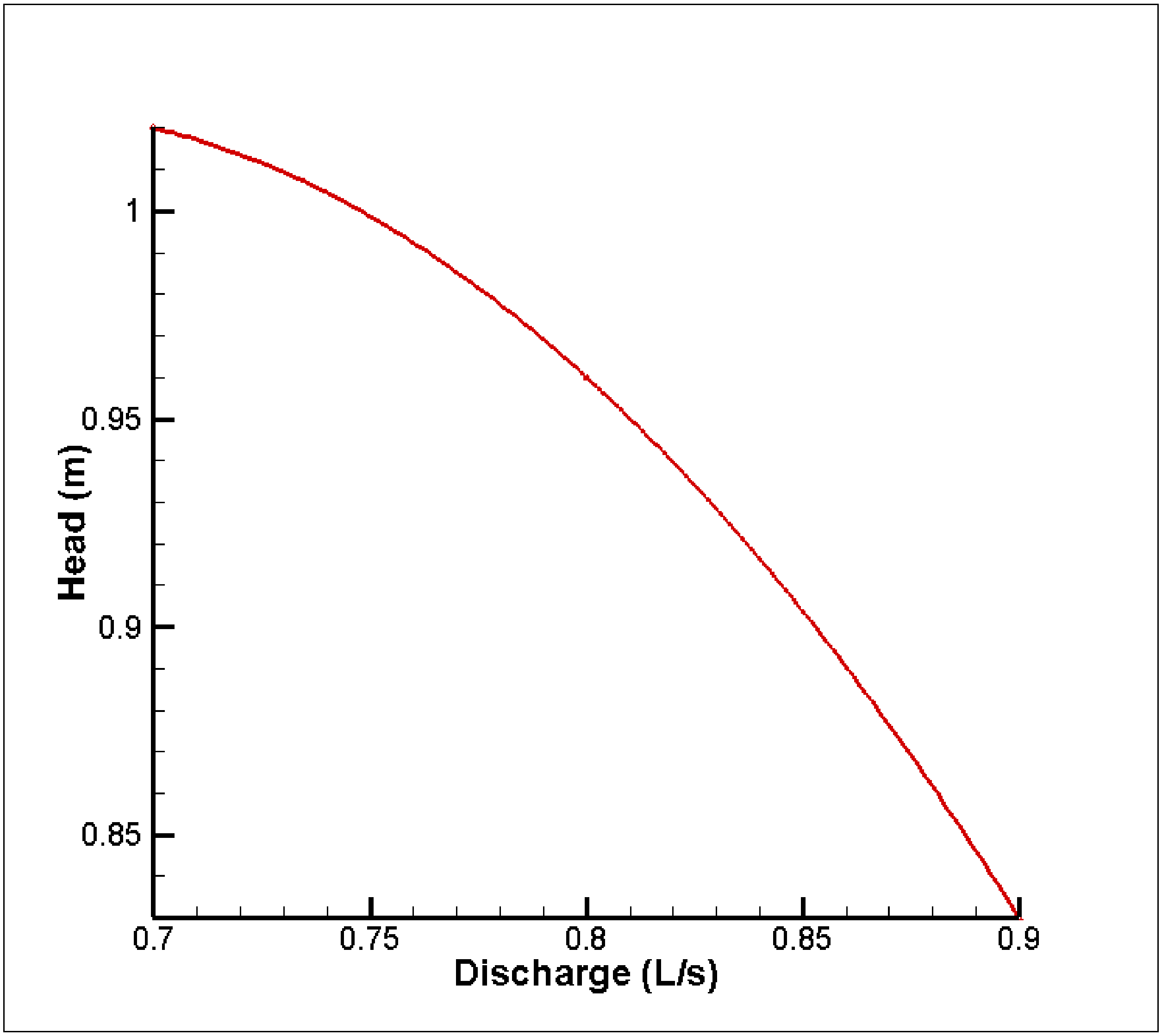

Figure 4. 5: plot of head(m) against discharge(L/s)

Figure 4. 5 shows the head(m) of the flow channel varied inversely with the discharge(L/s). At a head of 0.9 (m) at the beginning, the flow rate (discharge) was 0.83(L/s). when the head(m) was reduced the flow rate(discharge) was found to have a higher value (0.96(L/s)) compared to the later values. Thus, the flow rates will continue to increase as the head(m) decreases.

CHAPTER FIVE

5.0 CONCLUSION

Gravitational vortex hydraulic turbine power plant is capable of generating power from low water head. Therefore, this type of power plant is suitable for the areas with rivers. Since the fossil fuels reserves are declining, GVHTPP can be an alternative energy source which is environmentally friendly as well as cost effective. In this project the following results were obtained by designing, fabricating and varying the parameters of the system to determine the performance analysis of the gravitational vortex hydraulic turbine;

I. By doing this analysis we determine that the power produced by this turbine is of 369.5W, which helps in use of domestic purpose.

II. The head(m) varies inversely with the power(W), discharge(L/s), hydraulic, volumetric and mechanical efficiency.

III. The turbine is tolerant of muddy and polluted water, as the vortex action carriers small solid particles through the turbine. So the maintenance of this kind of turbine is less as compared to other type of turbines.

IV. The turbine, which operates at a low speed does not cut the natural stream of water so does not harm aquatic and marine life.

5.1 RECOMMENDATIONS

i. Tests should be carried out by varying flow rates on a different turbine blade design.

ii. The weight of the material of the shaft used should be reduced so as to increase efficiency and power.

iii. Hallow shaft should be used to increase torque

iv. The size of the channel (width) should be increased so the vortex formed and whirl velocity will increased, there by increasing torque.

v. Turbine fabrication should be carried out using better materials for weight reduction and increase in structural strength.

vi. Canal and notch angle optimization should be carried out to obtain better vortex in the basins.

vii. Tests should be carried out by changing the exit hole diameter to optimize the conical basin.

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