CARITAS UNIVERSITY AMORJI-NIKE, EMENE, ENUGU STATE

Caritas Journal of Physical and Life Sciences

CJPLS, Volume 1, Issue 1 (2022)

Article History: ***Received: 27th May, 2022*** ***Revised: 23th June, 2022*** ***Accepted:*** *.29th June, 2022*

DESIGN AND CONSTRUCTION OF A PELTON WHEEL TURBINE FOR POWER GENERATION

Ani, Hillary. O[1*]
Udeh Ubasinachi. O[2]
Utazi, Divine. N[3] .

[1]Department of Mechanical Engineering, Caritas University Amorji-Nike Enugu, Nigeria
[2]Department of Mechanical Engineering, Caritas University Amorji-Nike Enugu, Nigeria
[3]Department of Mechanical Engineering, Madonna University, Nigeria.
**Correspondence:* ani2hillary@gmail.com

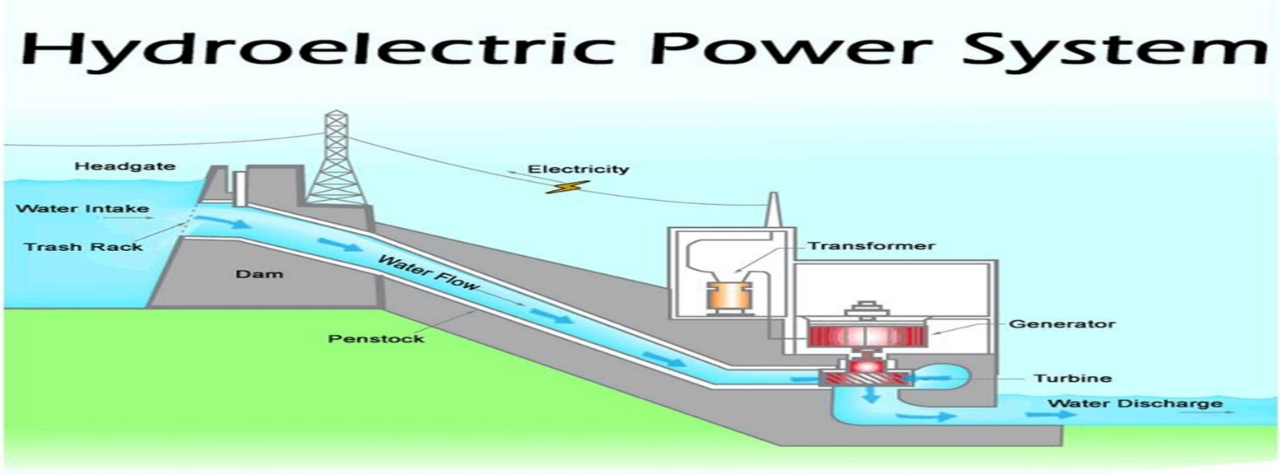
Abstract

Design and construction of a pelton wheel turbine for power generation is under taken. The pelton wheel turbine is a type of impulse turbine which under the atmospheric pressure and on this head which lies in the range of 200m. The pelton wheel turbine is an axial flow turbine. This work includes among other things the change in design parameter such as the change in discharge of water by which the velocity of jet changes due to change on the force exerted by the jet on the bucket which is responsible for the bucket movement which means the change in the speed of the runner with respect to the change in the jet velocity. The speed of the runner changes by two methods: first, is to change the discharge as well as the jet velocity which can be done by change in head and second, is the modification in the runner. Here the method used is changing the jet velocity by running at different and various height of 2.3m, 2m and 1.45m to ensure that experimental and calculations are made and graphical analysis obtained from the designed values.

Keywords: ***bucket, design and construction, pelton wheel turbine, jet velocity, speed of the runner***

Introduction.

Hydroelectric fig 1 power or Water electric power is also called hydropower, it captures electricity produced from generators driven by turbines that convert the potential energy of falling or fast-flowing water into mechanical energy (Hernandez.E, 2013). Hydro-energy is known as a traditional renewable energy source. It is based on natural circulating water flow and its drop from higher to lower land surface that constitutes the potential (Lahimer, A.A.,2015). In order to convert this potential to applicable electric energy, water flow should be led to and drive a hydraulic turbine, transforming hydro energy into mechanical energy, the latter again drives a connected generator transforming the mechanical energy into electric energy. As hydro energy exploitation and its utilization are completed at the same time. i.e. the exploitation of the first energy source and the conversion of the secondary energy source occur simultaneously, unlike the coal power generation which should have two orders; the first order is the exploitation of fuel, and the second order is the generation, so hydropower has the advantages over thermal power generation (Lahimer A.A, 2012).



Source:https://www.energy.org *Fig :1 Hydro Electric System*

Hydropower has been used since ancient times to grind flour and perform other tasks. In the late 18th century hydraulic power provided the energy source needed for the start of the Industrial Revolution. In the mid-1770s, French engineer Bernard Forest de Bélidor published Architecture Hydraulique, According to (Belidor, 2015) which described vertical and horizontal axis hydraulic machines, and in 1771 Richard Arkwright's combination of water power, the water frame, and continuous production played a significant part in the development of the factory system, with modern employment practices. In the 1840s the hydraulic power network was developed to generate and transmit hydropower to end users. By the late 19th century, the electrical generator. was developed and could now be coupled with hydraulics. The growing demand arising from the Industrial Revolution would drive development as well.
The technical potential for hydropower development around the world is much greater than the actual production: the percent of potential hydropower capacity that has not been developed is 71% in Europe, 75% in North America, 79% in South America, 95% in Africa, 95% in the Middle East, and 82% in Asia-Pacific (Sorensen.B,2004). Due to the political realities of new reservoirs in western countries, economic limitations in the third world, and the lack of a transmission system in undeveloped areas, perhaps 25% of the remaining technically exploitable potential can be developed before 2050, with the bulk of that being in the Asia-Pacific area. Some countries have highly developed their hydropower potential and have very little room for growth: Switzerland produces 88% of its potential and Mexico 80%. The construction of a hydroelectric complex can cause significant environmental impact, principally in loss of arable land and population displacement. They also disrupt the natural ecology of the river involved, affecting habitats and ecosystems, and the siltation and erosion patterns. While dams can ameliorate the risks of flooding, they also contain a risk of dam failure, which can be catastrophic (Hernandez. E, 2013).

Dams

A dam fig 2 is a structure constructed across a river or stream to keep water from flowing downstream. Over the years, many materials have been utilized to construct dams. Natural resources such as rocks and clay were utilized to construct ancient dams. Concrete is frequently used by modern dam builders. Manmade dams create artificial lakes called reservoirs (Weiss.A.M, 2006). Reservoirs can be used to store water for farming, industry, and household use. They also can be used for fishing, boating, and other leisure activities. People have used dams for many centuries to help prevent flooding. The ancient Mesopotamians may have been some of the first humans to build dams. The oldest known dam is the Jawa Dam, located in present-day Jordan. It was built in the fourth century B.C.E. Dams provided farmers with a steady source of water to irrigate crops (Jacques, 2019). This allowed ancient Mesopotamians to feed a growing population. They used dams to divert water for drinking, bathing, and irrigation. One of the oldest dams still in use is the Cornalvo Dam in Spain.
logs or grind corn and other grains. During the Industrial Revolution, engineers began to build bigger dams. These industrial-sized dams could hold back more water to power the big machinery of factories and mines. They also could turn giant turbines into 'generator Alternators' to generate alternating current. (Weiss, 2006)

Source:https://en.m.wikipedia.org/dam*Fig 2: A Dam.*

Generators

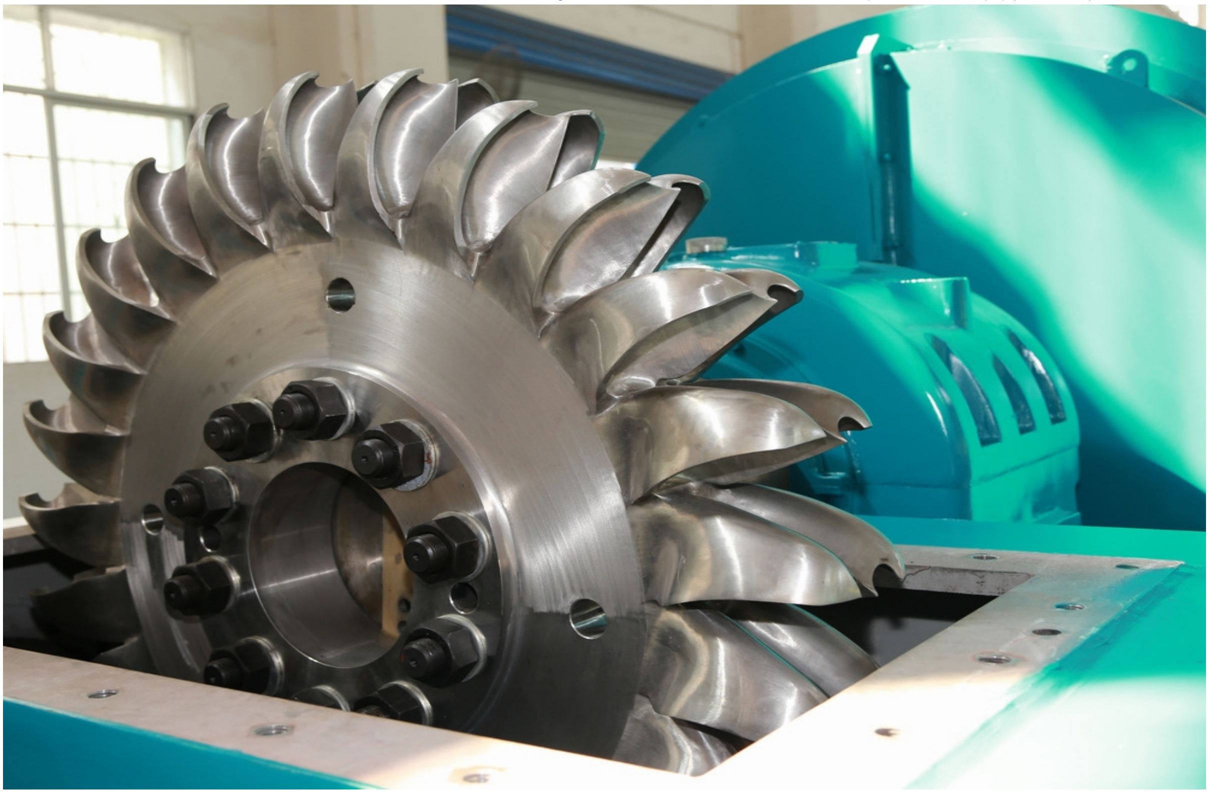
In an external circuit in electricity generation, a generator is a device that converts motive power (mechanical energy) into electrical power for use. Sources of mechanical energy include steam turbines, gas turbines, water turbines, internal combustion engines, wind turbines, and even hand cranks. The first electromagnetic generator, the Faraday disk, was invented in 1831 by British scientist Michael Faraday (Wayne,M.S,2002). Generators provide nearly all of the power for electric power grids. The reverse conversion of electrical energy into mechanical energy is done by an electric motor, and motors and generators have many similarities. Many motors can be mechanically driven to generate electricity; frequently they make acceptable manual generators. (Heller, 1896)

Mechanically a generator consists of a rotating part and a stationary part:

- **Rotor**: The rotating part of an electrical machine.
- **Stator**: The stationary part of an electrical machine, which surrounds the rotor.

Turbine

A turbine fig 4 is a rotary mechanical device that extracts energy from a fluid flow (in this case water) and converts it into usefull work. The work produced by a turbine can be used for generating electrical power when combined with a generator. A turbine is a turbomachine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. Early turbine examples are windmills and waterwheels (Hernandez, E 2013). Water turbines have a casing around the blades that contains and controls the working fluid. Credit for the invention of the steam turbine is given both to Anglo-Irish Engr. Sir Charles Parsons (1854–1931) for the invention of the reaction turbine, and to Swedish engineer Gustaf de Laval (1845–1913) for the invention of the impulse turbine. Modern steam turbines frequently employ both reaction and impulse in the same unit, typically varying the degree of reaction and impulse from the blade root to its periphery. (Ditina, 1998)



Source: https://www.peltonturbine.org/wheel*Fig 3:Turbine*

There are two main types of hydropower turbines:

- Reaction
- Impulse.

The type of hydropower turbine selected for a project is based on the height of standing water—referred to as "head"—and the flow, or volume of water over time, at the site. Other deciding factors include how deep the turbine must be set, turbine efficiency, and cost.

The working of principles of the Pelton Wheel Turbine

When the jet of water strikes the bucket (blade) attached to the wheel, it applies a force known as the "impulse force" to the bucket, water flows from the nozzle with high kinetic energy along a tangent to the route of the runner, the spear or needle attached to the end of a rod is furnished with the nozzle fitting at the end of the penstock in order to manage the amount of water striking the runner, the turbine receives the water's momentum throughout this procedure (Bryan,R.C, 2012). The turbine rotates because of the impulse force created by the motion of the water. The dual semi-ellipsoidal buckets divide the water jet into two half to assist in adjusting the wheels (runner). So that the fluid jet may smoothly transfer the motion to the turbine wheel . The turbine is built so that the water jet velocity is twice as fast as the bucket velocity for optimal power and efficiency, (Bryan,R.C, 2012). Pelton wheel turbine has buckets, rotor and housing as its components, and among others.

Bucket

Casting facilities is necessary because the Pelton turbine's buckets are to be produced locally. It must be cast as a single bucket, two buckets as in fig 7 or the entire rotor. It is possible to copy from other buckets that already exist when casting buckets for Pelton turbines (George,N.J, 2014). It is best to cast the individual buckets and then machine them into place on the rotor disk. Complex casting molds can be avoided in this way.If a suitable size is not available, the buckets can be made, if a copy milling machine is available, they can be made by decreasing or expanding existing buckets. Due to their weakness and ineffectiveness, manufacturing buckets made of half-pipe sections or other "ingenious" sheet metal section welding structures is not advised (Hernandez,E, 2013). Such ventures frequently came to a peaceful conclusion as another growing company failure after an enthusiastic start and a lot of labour. The jet is often disturbeb with each cutting of the water jet.. An unexpected and unwelcome diversion occurs in a portion of the water. This explains why picking a small number of buckets is advised (Nasir,B.A, 2013). However, if there are too few buckets, some of the water from the jet may miss one of them. The number of buckets affects the turbine's effectiveness but has no bearing on the runner's ideal speed.The biggest issue with free jet turbines, aside from manufacturing flaws like casting, alignment, and surface polish, is erosion of the buckets, especially where the water impinges on the buckets and because of sandy water or chemically aggressive compounds in the water (George,N.J, 2014).

Fig 4:Constructed Bucket of the pelton wheel turbine

Rotor

The rotor, wheel or runner of a Pelton turbine basically consists of a disk with a number of buckets fixed at its circumference as shown in fig 8. The disk is mounted on a shaft by means of a hub.The net head determines the velocity of the water jet and the peripheral velocity of the rotor (Lescohier, P.A, 2011). The pitch circle diameter (PCD) of the rotor can be calculated with the speed of the driven machine and the ratio of the transmission there are different methods of fixing the buckets to the rotor disk. If the buckets are bolted to the disk, each bucket must be connected to the disk with two bolts or with a bolt and a pin. The holes in the buckets and the disk should be drilled together and fit bolts or positioning pins should be used. To avoid loosening of the single buckets in circumferential direction, under the hammer-blow why the shape of the buckets is a key factor for the efficiency of the turbine (Nasir,B.A,2013). The surface finish of the buckets has a great influence on the efficiency and on wearing. That is why often not only the surface of the buckets is polished, but also the edges of the rear surface like force when the water hits the buckets, attempts were made to pre stress the buckets in peripheral direction by means of conical pins between the buckets. In combination with the internal stress of the casting, this resulted in uncontrolled pretension with local stress peaks in the area of the pins leading to "explosion" of the rotor (Hernandez, E,2013).On modem Pelton turbines very often the single buckets are fixed to the disk of the rotor by positive connection. This may be done with a type of dovetail on the buckets. The buckets are held by two disks by one disk and two ringsor by one disk and one ring, which are bolted together. This kind of fixation of the buckets to the rotor disk is expensive, but has a number of advantages. It can be used for high head application, because the foot of the buckets is not weakened by holes. The intention of giving these examples is to avoid similar mistakes in future (Weiss,A.M, 2006).

Fig 5:Constructed Rotor of the pelton wheel turbine

Housing (casing)

The housing of the Pelton turbine in fig 9, has the function of catching the splashed water and diverting it in such a way that neither the rotor nor the jet are disturbed (Weiss, A.M, 2006). It also serves to fix and hold the nozzles in place. The housing should be installed high enough above the tailrace water level so that the rotor does not plunge into the water. It must be manufactured strong enough to protect the surroundings in case of damage of a bucket or of the runner (Monson,B.B, 2009).

The housing of a Pelton turbine can be arranged either with a horizontal or with a vertical shaft. A shaft has the advantage that an optimal draining-off of the water is guaranteed and up to four jets can be installed (on large turbines up to six). In this arrangement optimal results are obtained when the side walls taper upwards by about 100. In this manner the water flows down helically (Jacques, 2019).

Fig 6: Constructed Housing of the pelton wheel turbine

The Design and Working Calculation

The head (H)

The head (H) of the Pelton wheel Turbine is designed to have three (3) Head levels with water filled in the head tank at levels of:

$$H_1 = H_{01} + h$$
$$H_2 = H_{01} + h_2$$
$$H_3 = H_{03} + h_3$$

Turbine wheel diameter
The diameter of the Pelton wheel turbine if 460mm
Nozzle Diameter, d
The Nozzle diameter of the Pelton wheel turbine used is 17mm =0.017m

Determination of Nozzle Area, A
The Nozzle Area of the cylindrical pipe is calculated from the formula:

$$A = \frac{\pi d^2}{4}$$

Nozzle outlet velocity is calculated from

$$V_n = C_v\sqrt{2gh}$$

Determination of mass flow rates. The mass few rate is

$$m = e\,AU$$

where
e = density
Determination of turbine speed
The Pelton turbine wheel is designed to run at half the water jet velocity, as this is where it will generate its maximum power
$\omega_{turb}(RPM) = 0.5 \times 1.91 \times 10^4 \times \frac{v_{jet}(m/s)}{d_{turb}(mm)}$ (Jacques, 2019)

Determination of generator speed

Chain and sprocket mechanism was introduced to increase the speed of the generator

Fig 7: constructed chain and sprocket of the pelton wheel turbine
Driving sprocket teeth is 48
Driven sprocket teeth is 14
$\frac{48}{14} = 3.43$

This implies the sprocket speed at the turbine(turbine speed) will be multiply by 3.43 to get the generator sprocket speed(generator speed).

$$\omega_{gen} = 3.43 \times \omega_{turb}$$

Power generation
The generalized equation for power generation of a DC generator is

$$p = k\phi\omega_{gen}$$

Calculations
The Heights of the Pelton wheel turbine to the base
1)$H_1 = H_{01} + h$
H_1 = 90 + 140 = 230 cm = 2.3m
2)$H_2 = H_{01} + h_2$
H_2 = 60 + 140 = 200cm = 2.0m
3)$H_3 = H_{03} + h_3$
H_3 = 5 + 140 = 145cm 1.5mm
Nozzle diameter = 17mm= 1.7cm = 0.017m

Wheel Diameter = mm460 = 46cm=0.46m
Nozzle out let velocity
$V_n = C_v\sqrt{2gh}$
When C_v= 0.98, coefficient of velocity

For Head H_1
H_1 =230 cm = 2.3m
Nozzle out let velocity
$V_1 = C_v\sqrt{2gh}$
$V_1 = 0.98\sqrt{2 \times 9.81 \times 2.3}$
$V_1 = 0.98\sqrt{45.126}$
$V_1 = 0.98 \times 6.718$
$V_1 = 6.584 m/sec$
Nozzle Area A
$$A_1 = \frac{\pi\, d^2}{4}$$
$$A_1 = \frac{3.124 \times 0.017^2}{4}$$
$A_1 = 0.0002257 m^2$
Water flow (jet) rate
$Q = V_1 \times A_1$
$Q = 6.584 \times 0.0002257$
$Q = 0.00149 m^3/sec$
Mass flow rate, m
$m = \varrho A u = \varrho Q$
Where ϱ is the density of water =1000kg/m^2
$$m = \varrho Q$$

$m = 1000 \times 0.0002257$

$m = 0.2257 kg/m^2$

Turbine speed

$$\omega_{turb}(RPM) = 0.5 \times 1.91 \times 10^4 \times \frac{v_{jet}(m/s)}{d_{turb}(mm)}$$

$$\omega_{turb} = 0.5 \times 1.91 \times 10^4 \times \frac{6.584}{460}$$

$\omega_{turb} = 136.69 RPM$

Generator speed

$\omega_{gen} = 3.43 \times \omega_{turb}$

$\omega_{gen} = 3.43 \times 136.69$

$\omega_{gen} = 468.85 RPM$

Power generated

$p = k\phi\omega_{gen}$

$p = 0.11 \times 0.10 \times 468.85$

$p = 5.2 watt$

For Head H_2

H_2= 200cm = 2.0m

Nozzle out let velocity

$V_2 = C_v\sqrt{2gh}$

$V_2 = 0.98\sqrt{2 \times 9.81 \times 2}$

$V_2 = 0.98\sqrt{39.24}$

$V_2 = 0.98 \times 6.264$

$V_2 = 6.139 m/sec$

Nozzle Area A

$$A_2 = \frac{\pi\, d^2}{4}$$

$$A_2 = \frac{3.124 \times 0.017^2}{4}$$

$A_2 = 0.0002257 m^2$

Water flow (jet) rate

$Q = V_2 \times A_2$

$Q = 6.139 \times 0.0002257$

$Q = 0.00139 m^2$

Mass flow rate, m

$m = \varrho A u = \varrho Q$

Where ϱ is the density of water =1000kg/m^2

$$m = \varrho Q$$

$m = 1000 \times 0.000139$

$m = 0.139 kg/m^2$

Turbine speed

$$\omega_{turb}(RPM) = 0.5 \times 1.91 \times 10^4 \times \frac{v_{jet}(m/s)}{d_{turb}(mm)}$$

$$\omega_{turb} = 0.5 \times 1.91 \times 10^4 \times \frac{6.139}{460}$$

$\omega_{turb} = 127.45 RPM$

Generator speed

$\omega_{gen} = 3.43 \times \omega_{turb}$

$\omega_{gen} = 3.43 \times 127.45$

$\omega_{gen} = 437.15RPM$

Power generated

$p = k\phi\omega_{gen}$

$p = 0.11 \times 0.10 \times 437.15$

$p = 4.8watt$

For Head H_3

$H_3 = 5 + 140 = 145$cm 1.5mm

Nozzle out let velocity

$V_3 = C_v\sqrt{2gh}$

$V_3 = 0.98\sqrt{2 \times 9.81 \times 1.5}$

$V_3 = 0.98\sqrt{29.43}$

$V_3 = 0.98 \times 5.425$

$V_3 = 5.317m/sec$

Nozzle Area A

$$A_3 = \frac{\pi\, d^2}{4}$$

$$A_3 = \frac{3.124 \times 0.017^2}{4}$$

$A_3 = 0.0002257m^2$

Water flow (jet) rate

$Q = V_3 \times A_3$

$Q = 5.317 \times 0.0002257$

$Q = 0.00120m^2$

Mass flow rate, m

$m = \varrho Au = \varrho Q$

Where ϱ is the density of water =1000kg/m^2

$$m = \varrho Q$$

$m = 1000 \times 0.000120$

$m = 0.12kg/m^2$

Turbine speed

$$\omega_{turb}(RPM) = 0.5 \times 1.91 \times 10^4 \times \frac{v_{jet}(m/s)}{d_{turb}(mm)}$$

$$\omega_{turb} = 0.5 \times 1.91 \times 10^4 \times \frac{5.317}{460}$$

$$\omega_{turb} = 110.39RPM$$

Generator speed

Head (m)	Power (watt)
2.3	5.2
2.0	4.8
1.5	4.2

$$\omega_{gen} = 3.43 \times \omega_{turb}$$

$$\omega_{gen} = 3.43 \times 110.39$$

$$\omega_{gen} = 378.64RPM$$

Power generated

$$p = k\phi\omega_{gen}$$

$$p = 0.11 \times 0.10 \times 378.64$$

$$p = 4.2watt$$

1) Plot of power (P) Versus Head:
   Tables 2: Head (m) /power (watt)

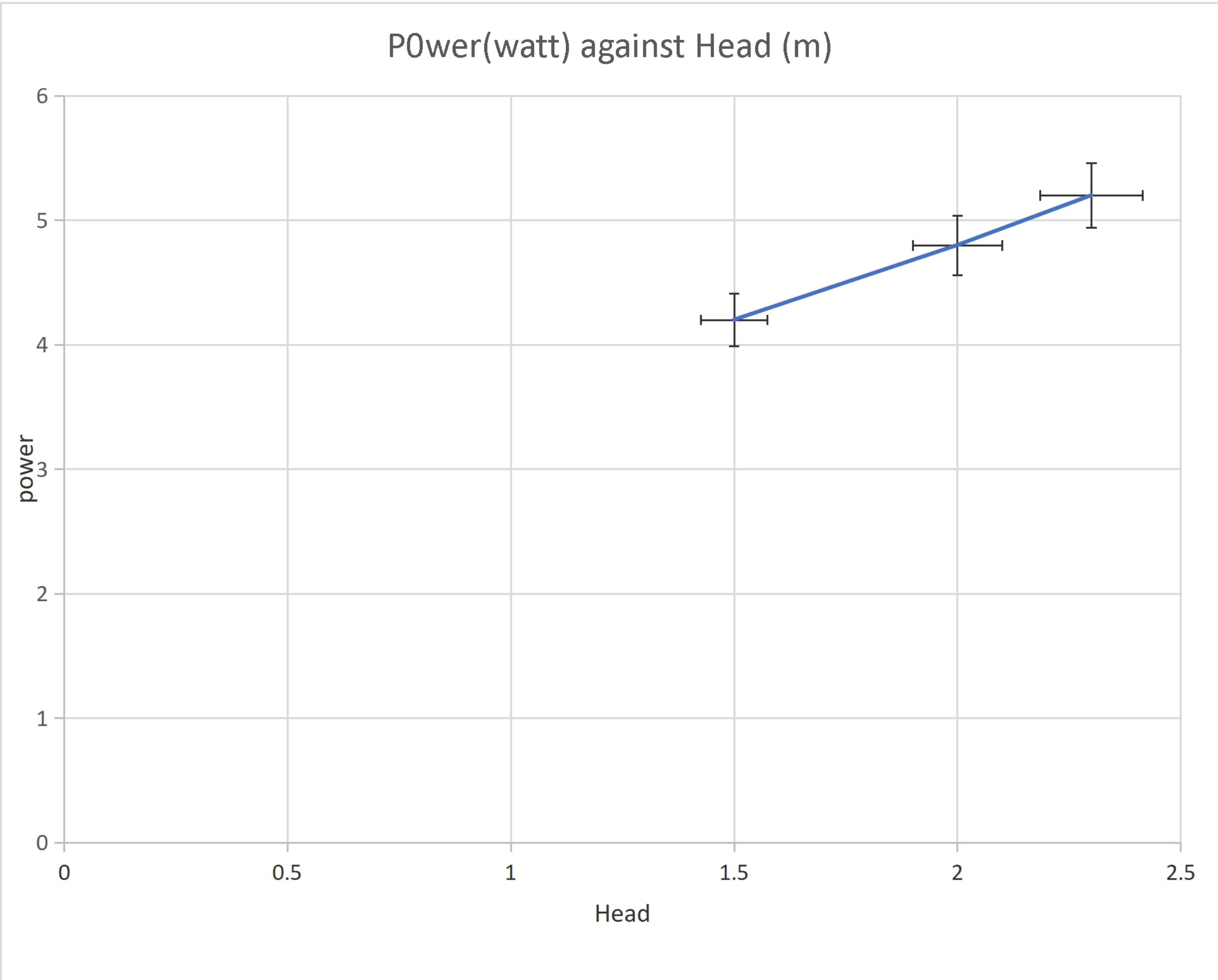


Fig8: plot of power against head

Plot of power (P) versus mass flow rate

Table 3: Head (p) versus mass flow rate

Head (m)	Mass flow rate (kg/m^2)
2.3	0.23
2.0	0.14
1.5	0.12

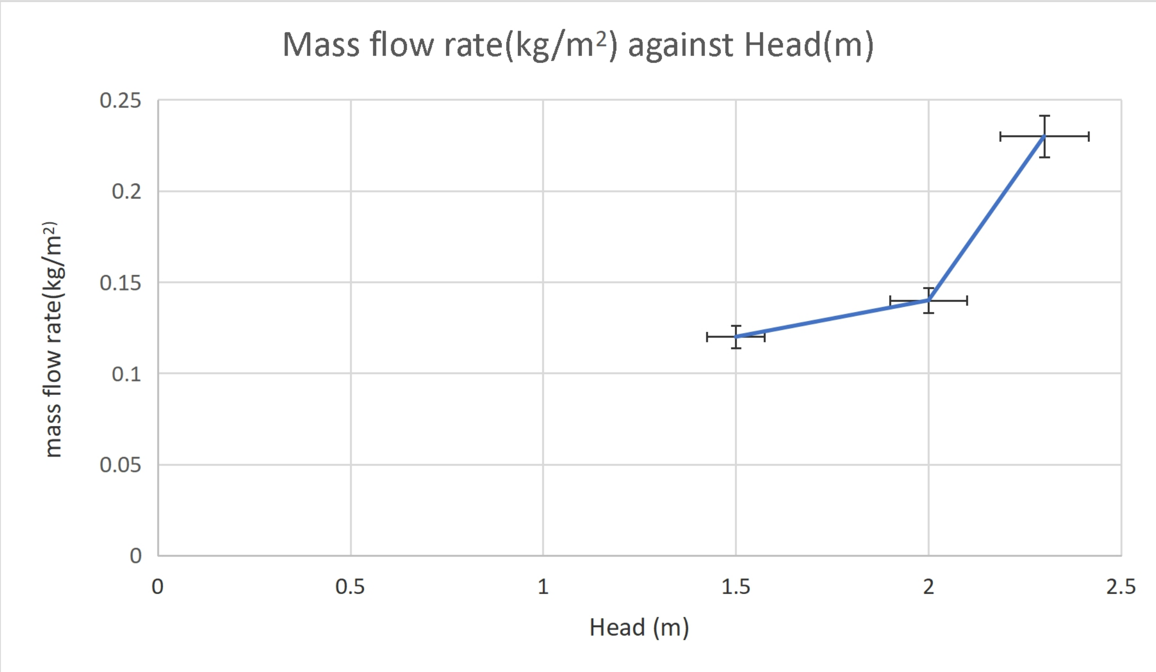


Fig9: plot of mass flow rate against head

Experimental result

Table 4Experimental result table

S/N	Head	Volumetric flow rate	Power generated
1	2.3	6.584	4.9
2	2.0	6.139	4.4
3	1.5	5.317	3.9

Plot of power (P) Versus Head

Table 5 Plot of power (P) Versus Head

Head (m)	Power (watt)
2.3	4.9
2.0	4.4
1.5	3.9

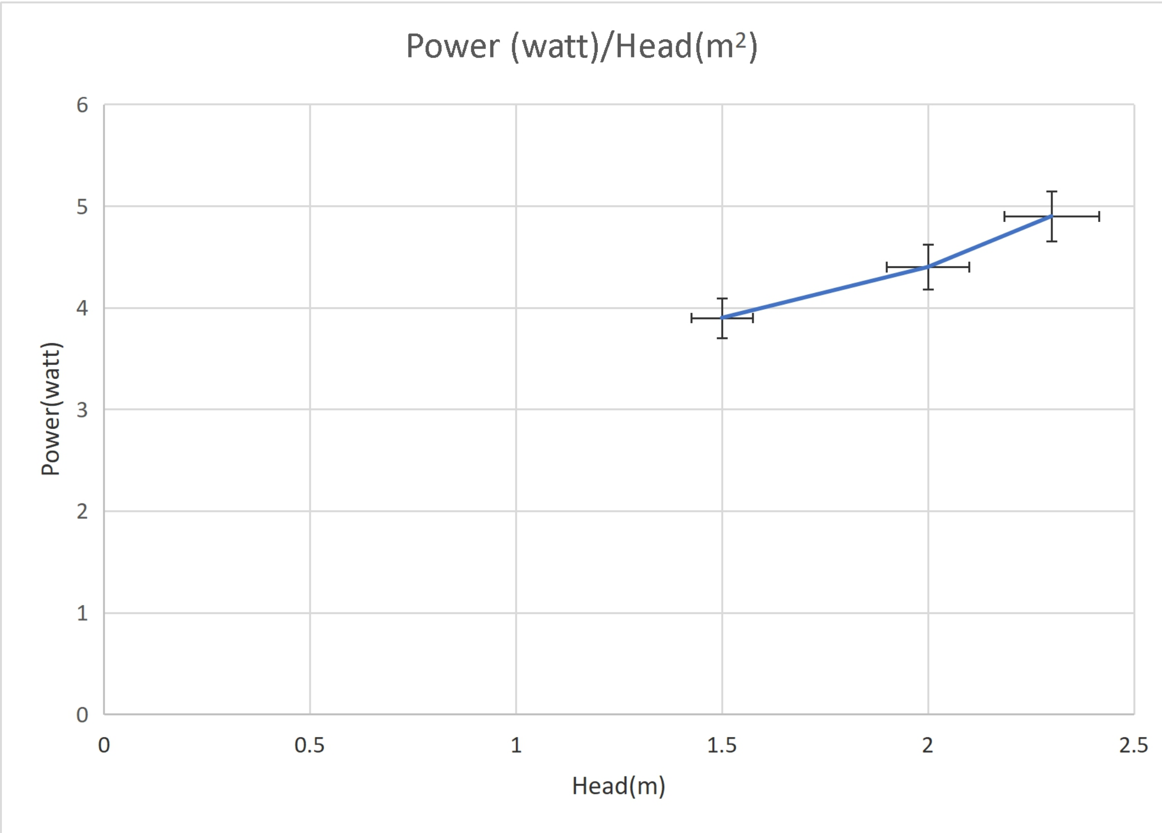


Fig 10: plot of power(P) versus Head(H)

Plot of power (P) versus volume flow rate

Table 6: Plot of volume flow rate against Head

Head (m)	Volume flow rate (m/sec)
2.3	6.584
2.0	6.139
1.5	5.317

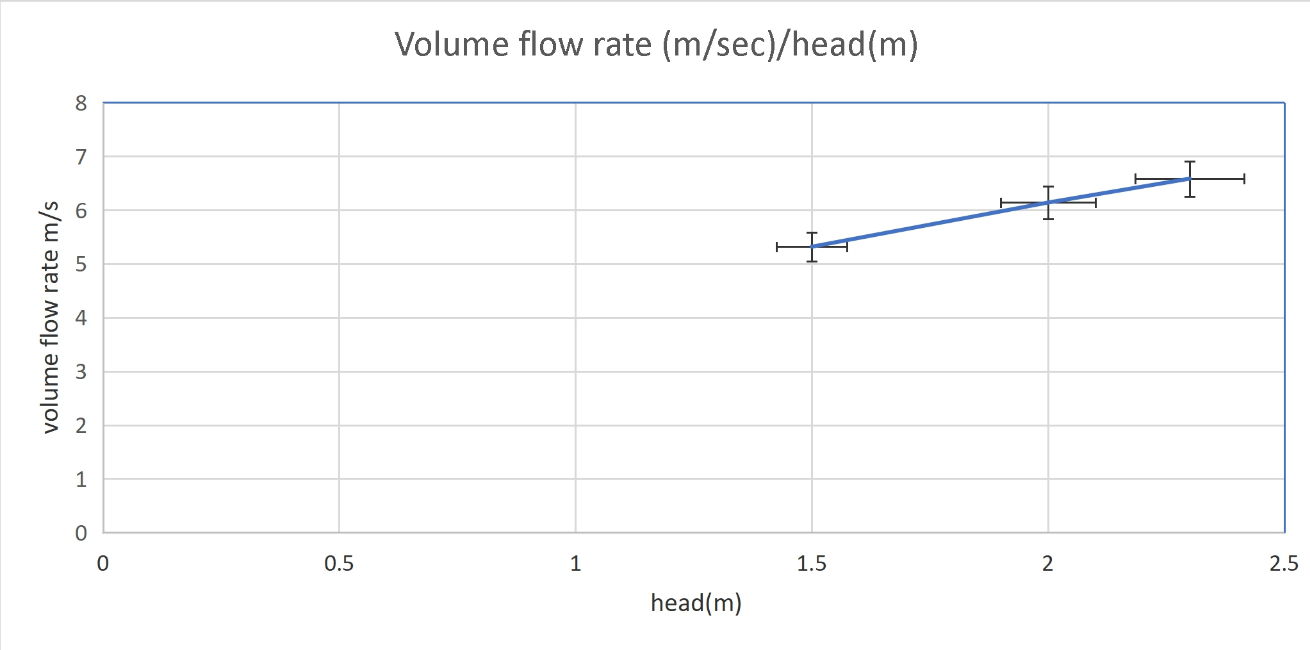


Fig 11: Plot of volume flow rate against Head

Discussion

The difference in calculated result and experimental result is considered to be due to the losses and leakages along the flow line and equally the frictional losses along the pipe

Conclusion

From the experiment and calculations, it was observed that;
1, The volumetric flow rate is dependent on the nozzle area and Velocity of the jet.
2 The mass flow rate is dependent on the volumetric flow rate
The head, H is a function of the power generated. The Pelton wheel Turbine is very economical to construct, and equally has the advantage of power delivery over a small area of water reservoir.
The turbine head is varied on the heights of 230cm, 200cm, and 145cm to ensure that experiment and calculations are made and graphical analysis obtained from the designed values.

Recommendation

1. It is recommended that the wheel of the turbine (w), the head (h) and the volume of thank be increased for more power generation.

2. The Pelton wheel turbine efficiency is to be increased by ensuring that losses of flow due to leakages are minimized. The power generated increased, with increase in the head (H) level, and the increase in head (H) increased the flow velocity.

References

Belidor, B. F. (2015). *Architecture Hydraulique.* india: Facsimile publisher.

Bryan, R. C. (2012, August 10). Impulse (Turgo and pelton) turbine performance characteristics and their impact on picohydro installations. pp. 15-18.

Ditina, P. S. (1998). *Hydroulic turbine basic principle and state of threat computational fluid dynamic application.* Chicago: proclnstn mech engr.

George, N. J. (2014). *Static Analysis on Pelton Wheel Bucket.* washington: IJERT.

Heller, A. (1896). Anianus Jedik. *Nature normal* , 58.

Hernandez, E. (2013). Design and construction of an impulse turbine. *Journal of physics conference series* , 466.

Jacques. (2019). *pump fundamentals*. Retrieved from www.pumpfundamentals.com: https://www.pumpfundamentals.com/micro-hydro_formulas.htm

Lahimer A.A, A. M. (2012). *Research and development aspects of Picohydro power.* ELSEVEIR.

Lescohier, P. A. (2011). Lester Pelton and pelton water wheel. *Nevada county historical society* , 45.

M, T. J. (1991). *MICHAEL GARADAY AND THE ROYAL INSTITUTE.* NEW YORK: THE GENUIUS OF MAN AND PLATE.

Monson, B. B. (2009). *Fundamental of fluid mechanics.* (K. Hoboken, Ed.) Wiley, J and sons.

Nasir, B. A. (2013). *Design of High Efficiency Pelton Turbine for Micro Hydro Power Plan* (Vol. 4). IJET.

Sorensen, B. (2004). Renewable energy. *Rcademic press* , 55.

Thomas, J. M. (1991). *Michael Faraday And Royal Institute.* New York: The genuius of man and placd.

Wayne, M. S. (2002). Faraday Law of Electromagnetic Induction. In M. S. Wayne, *Electricity, Magnetism, and Light* (pp. 505-558). Texas: Elsivier.

Weiss, A. M. (2006, Novembe 3rd). Unsteady analysis of Pelton runner with flow and mechanical simulations. *Hydropower & Dams,* , p. 22.