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Performance Analysis ofTablespoon Buckets Impulse Turbine

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ABSTRACT
This paper presents the performance analysis of a Tablespoon Buckets Impulse Turbine. It is a hydro mechanical energy conversion device that converts hydraulic energy of elevated water into mechanical works; hence it is an axial flow impulse turbine used for high head of water. The performance analysis involves the study of the effect of the designed and flow parameters such as the size of the buckets, number buckets, nozzle diameter, diameter of wheel, the diameter of the jet, the head of water, the velocity of the wheel and the velocity of the water jet on the power produced by the impulse turbine, hydraulic efficiency, mechanical efficiency and overall efficiency. TheTablespoon Impulse Turbine consists of an electric pump of 0.5HP, with a power unit consisting of the dynamo, cables, multimeter, LED bulbs, and socket. The diameter of the wheel is 0.17m, diameter of the jet is 0.03m and manufacturer designed pump head is 35m. Other designed parameters are a 6volt, 3watt dynamo used to serve as the generator which through its rotation caused by the power shaft can produce electricity. Thedevice was designed and manufactured. Employing the working principle, the performance of the turbine was analysis and it was observed to be in good agreement with other existing impulse turbines. The results show that as the diameter of the jet increases, there is a corresponding increase in the discharge, hence an increase in efficiency of the impulse turbine and vice versa. The hydraulic efficiency (η_h) % this impulse turbine was computed as97.3%, which is in good agreement with a standard Rajput (2008) experiment.

KEYWORDS: *Tablespoon, Pelton, Wheel, Impulse, Turbine, Power, Generation.*

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I. INTRODUCTION

The Tablespoon Buckets impulse turbine is a form of a Pelton wheel. It is a hydro mechanical energy conversion device that converts hydraulic energy of elevated water into mechanical works; hence it is an axial flow impulse turbine used for high head of water. It is a rotary engine that extracts energy from a fluid flow and converts it into useful mechanical work (Rajput, 2008). ThePeltonwheel impulse turbine converts gravitational energy of elevated water into mechanical work. This mechanical work in turn is converted into electrical energy by means of running electrical generator. It is essential to note that, the Pelton wheel is a form of hydraulic turbine that makes use of water for its operation. Considering water as one of the sources of energy, falling water contains stored hydro energy which can be converted to other forms of energy such as mechanical energy for useful work. This is possible since the energy will causethe rotation of a shaft carrying buckets to produce power thereby producing electricity.ThisPelton wheel is a tangential flow free jet impulse turbine whose nozzle transforms water under a high head into a powerful jet. In this turbine, all of the kinetic energy of the jet is transformed into mechanical energy, giving rise to a high efficiency of the turbine. This type of free-jet water turbine was first introduced by an American; named *Lester Pelton* in 1870 and the device is called the Pelton Wheel or Pelton turbine Rajput (2008).

Pelton Turbines has been widely used in hydroelectric plants in the northern part of Nigeria example is the kanji dam power generation system. The extraordinary versatility of electricity as a source of energy for our industrialised society informed the performance analysis of the Tablespoon Buckets Impulse turbine ascertain the power output of the manufactured mini impulse turbine.

II. BACKGROUND AND REVIEW OF PREVIOUS WORK ON THE PELTONWHEEL (IMPULSE TURBINE)

This section presents the background and review of the Pelton wheel which is an Impulse turbine. A review of previous work relating to the designed and has been extensively discussed. The Pelton wheel was first invented by an American inventor, Lester Allen Pelton in 1870s. Shinde1, A. D. and Shelke S. N. (2016) confirm in their study that the dynamic characteristics of a hydro turbine power depend heavily on changes in load disturbances. Thus the hydro turbine exhibits highly nonlinear, non-stationary system whose characteristics vary significantly with the unpredictable load. Nasir, B. A. (2013)design of high efficiency Pelton turbine for micro hydropower plant and obtain a Pelton hydraulic turbine with maximum efficiency during various operating conditions and the turbine parameters such as turbine power, turbine torque, runner diameter, runner length, runner speed, bucket dimensions, number of buckets, nozzle dimension and turbine specific speed were investigated. According to Prajapati1 V. M.*et al.* (2015), a complete design of impulse turbines has been presented based on theoretical analysis and some empirical relations. The maximum turbine efficiency was found to be 97% constant for different values of head and water flow rate. The complete design parameters such as turbine power, turbine torque, turbine speed, runner dimensions and nozzle dimensions are determined at maximum turbine efficiency using the MATLAB software.

Ishola, A. F. *et al.* (2019) undertook a study, the design and analysis of a Pelton wheel turbine model for a Pico-sized hydropower system powered by rainwater collected on rooftops which is capable of producing the power required for certain functions like charging handsets, mini gadgets and low energy lighting purposes which are very essential in most communities in Nigeria instead of using the generator powered by gasoline which are very costly.Oo, T. Z.*et al.*(2019) carried out a research on the manufacturing of a Pelton turbine that will be capable of generating 220 kW output power from head of 213 m and flow rate of 0.135 m3/s. For this head and capacity of turbine, rotational speed is 1000 RPM, specific speed is 18.4, pitch circle diameter is 0.56 m, jet diameter is 0.053 m and nozzle outlet diameter is 0.064 m. The effect of different nozzles, water head and discharge on the performance of the Pelton turbine system was experimentally investigated by Farge, T. Z *et al*. (2017). The effect of five different nozzles with outlet diameters of (3.61,5.19, 8.87, 12, and 14.8) mm has been studied. They came to the conclusion that for every certain nozzle, decreasing the water head lead to reduction in water discharge and this caused a reduction in the torque, brake power, efficiency and the rotational speed. According Sarab*et al.* (2013), the electrical energy can be put to use in the following areas of need, these include heating, lighting, and communications, among others, noting that electrical power is the backbone of modern industrial society, and is expected to remain so for the foreseeable future. But due to the nature of the energy sector in our country Nigeria faced with challenges such as inadequate power supply due to the high cost of maintenance of its power facilities, poor management systems, and government policies amongst others; there is a need for a mini sustainable means of power generation in a small scale where individuals can depend on for small scale use Garry and Akata(2002), giving rise to this simplest mini turbine. The goal of this work is to use the impulse type water turbine such as the Tablespoon Buckets Impulse turbine to generate mechanical power, which in turn can produce electrical energy.

III. DESIGN OF THE TABLESPOON BUCKETS IMPULSE TURBINE

The following parameters were considered with their usual notation, concepts and formulae in the design of the turbine; thisincludes bucket and a number of bucket, jet ratio, the velocity of the wheel (u), the velocity of the jet (v), speed ratio, specific speed, nozzle diameter, diameter of wheel, the diameter of the jet, the head of water, and the velocity of the water jet, power and efficiency of the impulse turbine. Manufacturing software and machine tools were employed from the design phase to the manufacturing phase of this turbine. From Figure 3.1 to Figure 3.3, shows the development process of the Tablespoon Impulse turbine from the CAD design through to the fabrication, assembling and installation of parts of the finished product.

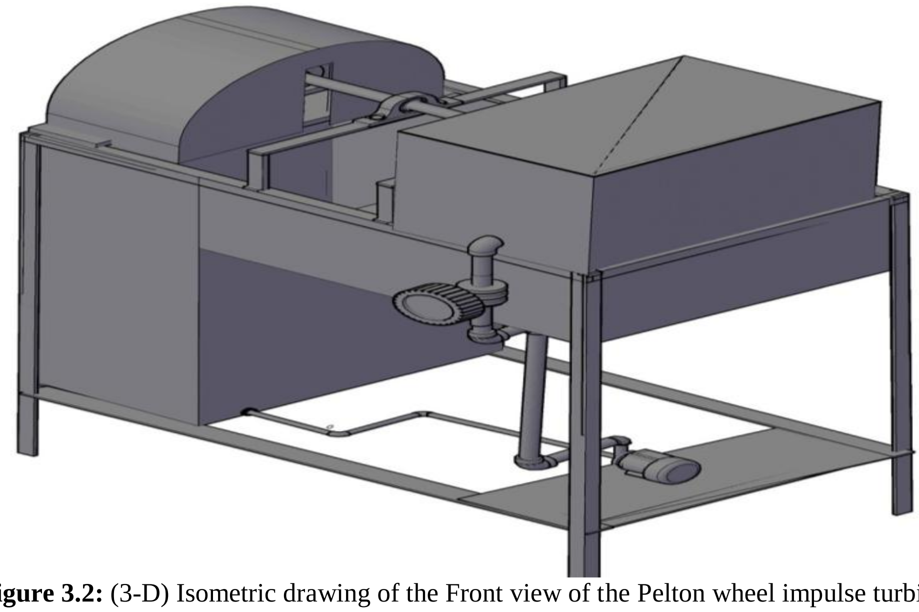

Figure 3.2: (3-D) Isometric drawing of the Front view of the Pelton wheel impulse turbine

	
a) The Fabricated Runner	b) The Tablespoon cut to the required bucket length
	
c) The Tablespoon and Runner ready to be weld together	d) The wheel of the Impulse turbine is ready for Installation

Figure 3.3: Fabrication of the Runner and the Tablespoon buckets

Figure 3.1 shows the Isometric drawing of the Front views of the Pelton wheel impulse turbine while Figure 3.2 (a-d) shows the fabricated runner and the Tablespoon buckets. Figure 3.3 is the finished Pelton wheel in AkwaIbom State University's workshop ready for used.

Figure 3.4: The Manufactured Pelton wheel (Impulse Turbine) in AkwaIbom State University's Workshop

IV. RESULT AND DISCUSSION

This section presents the results and discussion of this work. Section 4.1 discusses the working principle and the operational procedure of the machine, Section 4.2 presents the performance analysis the Tablespoon Buckets Impulse turbine; this includes result analysis of the variation of nozzle diameter with discharge, pressure and power develops and available at the nozzle, and finally the hydraulic efficiency of the turbine is presented.

4.1 Working principle of the Pelton wheel

The working principle of Pelton wheel (an impulse turbine) is based on the principle of energy conversion. The Peltonwheel turbine is a good example of the energy converting machine. The Pelton wheel turbine consists of a rotor, at the periphery of which is mounted equally spaced hemispherical buckets. Water is transferred from a high head source through the penstock (pipe) which is fitted with a nozzle, through which the water flows out at a high speed jet. A needle spear moving inside the nozzle controls the water flow and at the same time provides a smooth flow with negligible energy loss. All the available potential energy is thus converted into kinetic energy before the jet strikes the buckets of the runner. The pressure all over the wheel is constant and equal to the atmosphere, so that energy transfer occurs due to purely impulse action. As the runner rotates after its buckets have received the water jet, a shaft coupled directly to the runner also rotates due to the mechanical energy been transferred to it by the runner. Consequently, a dynamo being attached to the shaft through a pulley belt system rotates due to the conversion of mechanical energy to electrical energy and power is produced Rajput (2008). The size and diameter of the water jet going out of the nozzle is dependent on the diameter of the nozzle. A bigger capacity of the generator can be used in order to generate a greater power depending on intending usage.

4.2 Performance evaluation of the Tablespoon Buckets Impulse turbine

Performance characteristics of the apparatus were investigated during operation and were analysed and presented in Table 4.1 to Table 4.4. The performance results were also presented graphically in terms of discharge, operating pressures at different range, the output power at a constant head and the hydraulic efficiency of the turbine was analysed. The result obtained was recorded based on the operational details of the Pelton wheel by the manufacturer with a designed head of water of 35m. In this study, nozzle diameter is presented as a function of the control valve opening position in percent (%). The valve positions were divided into four (4) quadrants of 1/4, 1/2, 3/4 and full open position of the valve; giving 25%, 50%, 75% and 100% opening positions respectively. However, a fifth opening position at 4/5 which is equal to 80% was added to allow for a better understanding of the operations.

Table 4.1: Shows the operational details of the Tablespoon Bucket Pelton wheel

S/N	**Control valve opening position**	**Position in Percent (%)**	**Pressure reading (bar) 1bar =14.5 psi**	**Discharge (Q) (L/min.)**
1	Valve fully closed	0%	0	0
2	Valve opens at $\frac{1}{4}$	25%	0.5	2.4
3	Valve opens at $\frac{1}{2}$	50%	1.03	4.4
4	Valve opens at $\frac{3}{4}$	75%	1.06	6.8
5	Valve opens at $\frac{4}{5}$	80%	1.08	7.2
6	Valve fully opened	100%	1.37	8.6

Figure 4.1 shows the effect of nozzle diameter on the pressure of the turbine. It observed from the Table 4.1when the spear or valve which controls the flow of the water jet going out from the nozzle is open gradually, the pressure of the turbine increases accordingly up to a point where the valve is fully opened and maximum speed of the turbine is obtained as the water jet is impinging on the series of buckets.

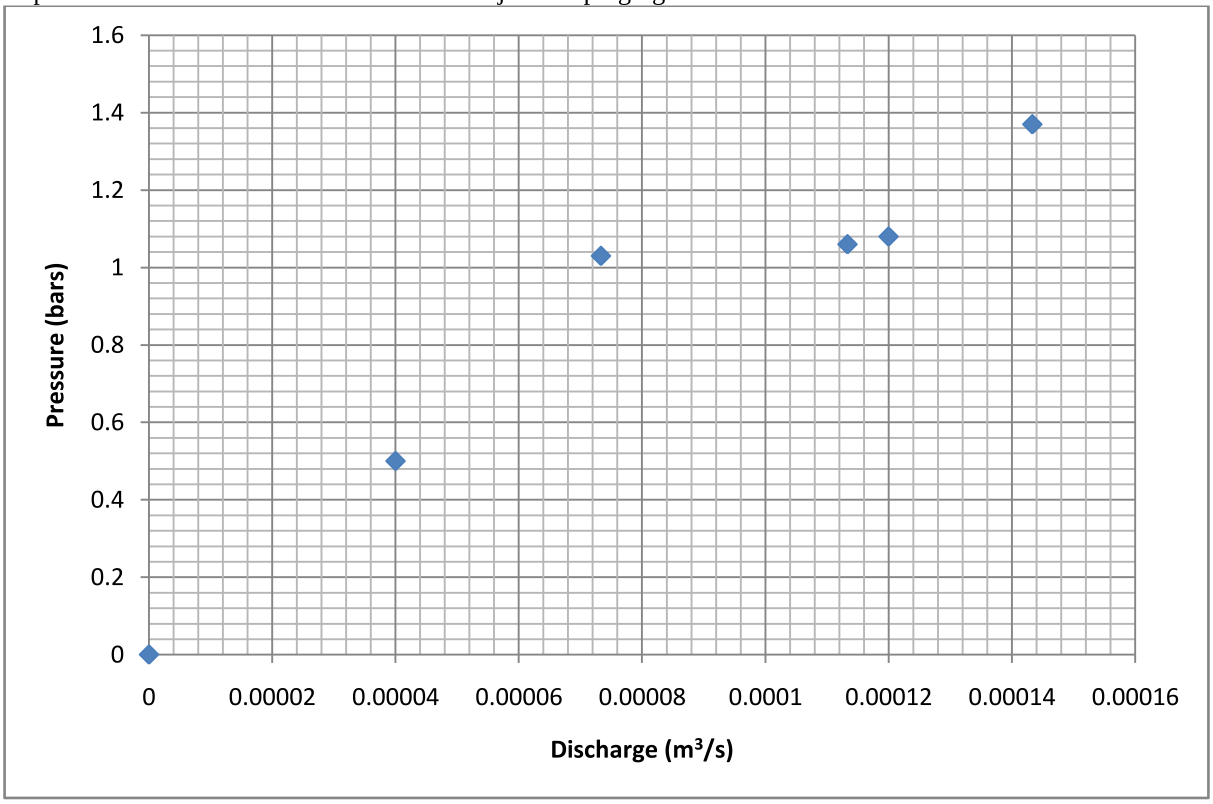

Figure 4.1: Shows the effect of Nozzle diameter on the Pressure of the turbine

It is also observed from Table 4.1, that as the valve position is adjusted outward, the flow rate increases and more discharge from the nozzle are obtained; this is presented graphically as Figure 4.2, resulting in a higher efficiency. Table 4.2 shows the discharge conversion from litres per minute to cubic metre per seconds at each control valve opening position.

Table 4.2: The discharge conversion at each valve control opening position

S/N	**Control valve opening position**	**Position in Percent (%)**	**Discharge (Q) (Litres/min.)**	**Discharge (Q) (Litres/s)**	**Discharge (Q) m^3/s**
1	Valve fully closed	0%	0	0	0
2	Valve opens at $\frac{1}{4}$	25%	2.4	0.04	0.00004

3	Valve opens at $\frac{1}{2}$	50%	4.4	0.0733	0.00007333
4	Valve opens at $\frac{3}{4}$	75%	6.8	0.1133	0.0001133
5	Valve opens at $\frac{4}{5}$	80%	7.2	0.12	0.00012
6	Valve fully opened	100%	8.6	0.1433	0.0001433

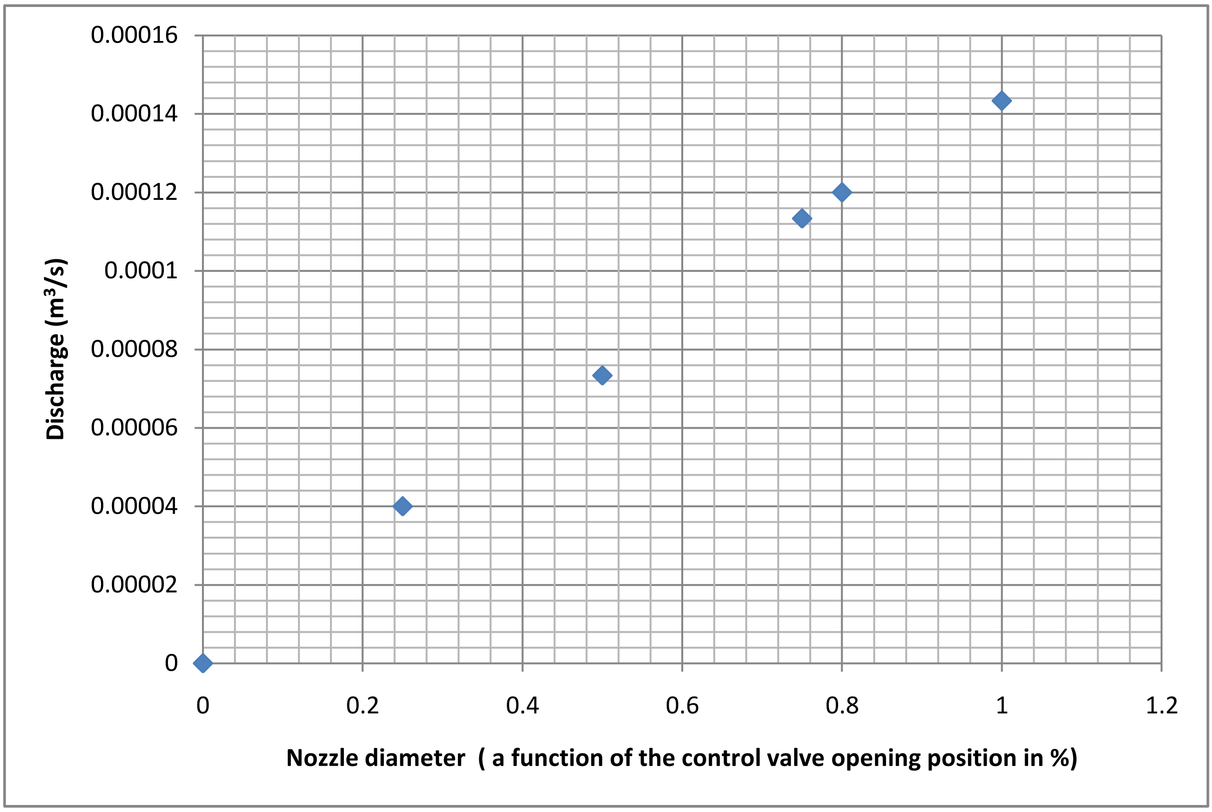

Figure 4.2: Shows the effect of Nozzle diameter on the Discharge of the turbine

Table 3 shows the variation of pressure and discharge with respect to the valve control opening position and is presented graphically as Figure 3.3. This indicates that, an increase in the diameter of the nozzle brings about an increase in the flow discharge with more pressure.

Table 4.3: Shows the Pressure variation with Discharge of the Tablespoon Pelton wheel turbine

S/N	Control valve opening position	Position in Percent (%)	Pressure reading (bar) 1bar =14.5 psi	Discharge (Q) (L/min.)	Discharge (Q) m^3/s
1	Valve fully closed	0%	0	0	0
2	Valve opens at $\frac{1}{4}$	25%	0.5	2.4	0.00004
3	Valve opens at $\frac{1}{2}$	50%	1.03	4.4	0.00007333
4	Valve opens at $\frac{3}{4}$	75%	1.06	6.8	0.000113
5	Valve opens at $\frac{4}{5}$	80%	1.08	7.2	0.00012
6	Valve fully opened	100%	1.37	8.6	0.000143

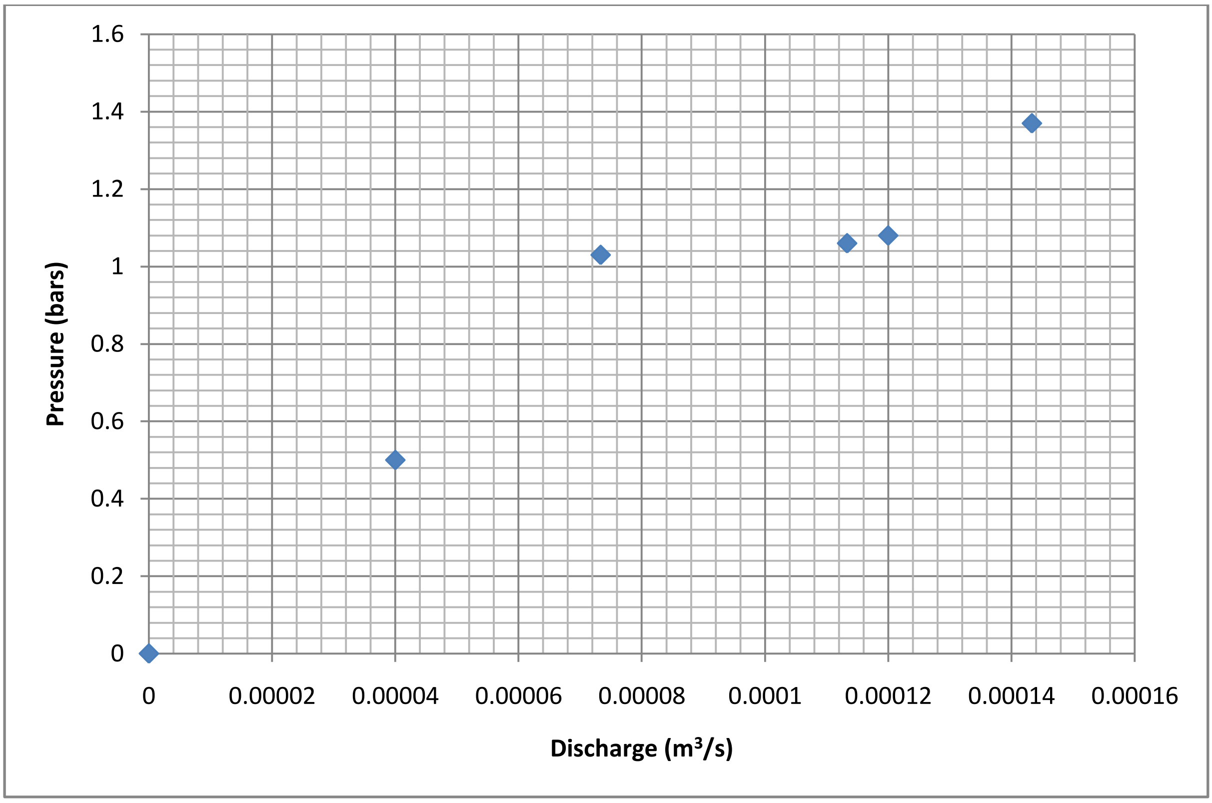

Figure 4.3: Shows the variation of Pressure with the Discharge of the TablespoonPelton wheel turbine

4. 2. 2 Power available at Nozzle per discharge rate

The power available at the nozzle of the turbine per discharge was analysis and presented in Table 4.4. This is shown graphically as the power available variation with discharge in Figure 4.4.

Table 4.4: Shows valve opening position, corresponding discharge against power

S/N	Control valve opening position	Position in Percent (%)	Discharge (Q) m^3/s	Power (W)
1	Valve fully closed	0%	0	0
2	Valve opens at $\frac{1}{4}$	25%	0.00004	13.36
3	Valve opens at $\frac{1}{2}$	50%	0.00007333	24.50
4	Valve opens at $\frac{3}{4}$	75%	0.0001133	37.85
5	Valve opens at $\frac{4}{5}$	80%	0.00012	40.10
6	Valve fully opened	100%	0.0001433	47.87

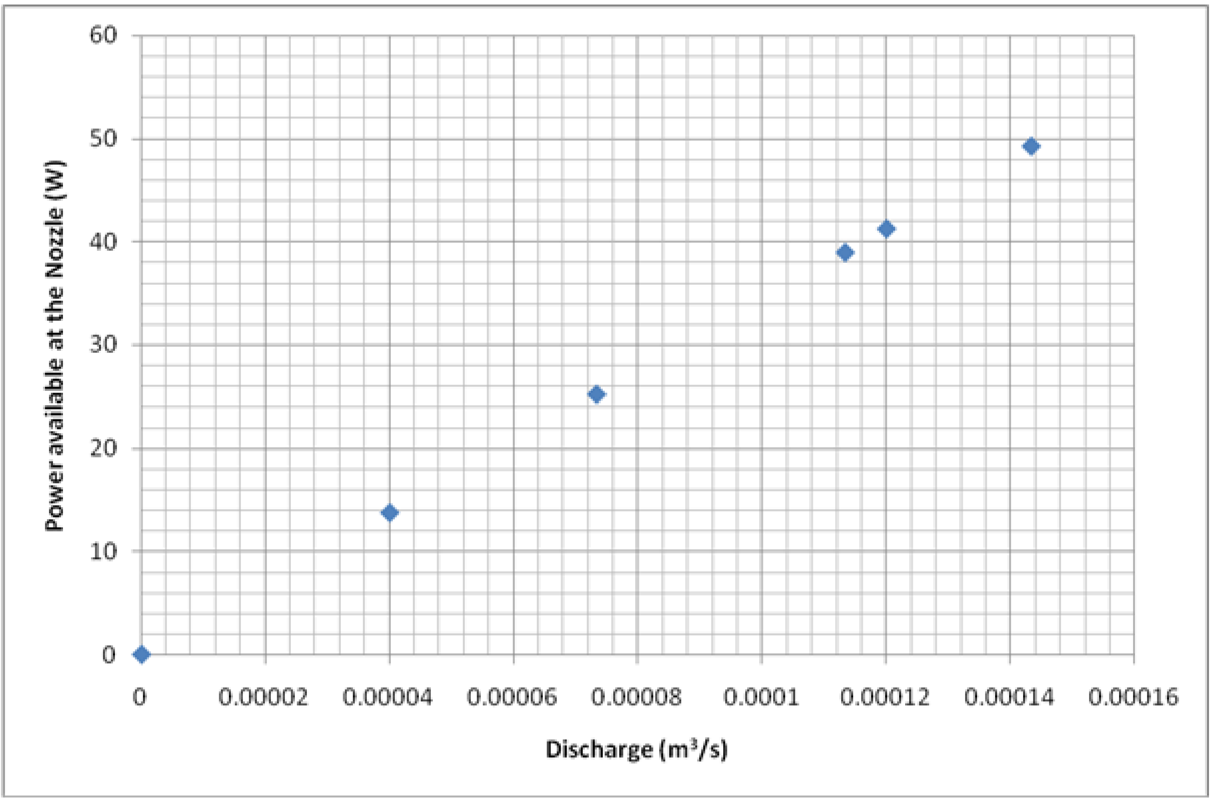

Figure: 4.4: Graph of Power available at the nozzle against Discharge of the turbine

The result shows that as the turbine speed increase, there is an increase in the power output, hence, a corresponding increase in the flow discharge.

4.2.3The Power available at the nozzle

The power given by the water to the runner can be analysis using the triangle velocity diagram of Figure 4.5 showing both the inlet velocity triangle and outlet velocity triangle respectively. All the notations retain their usual meaning.

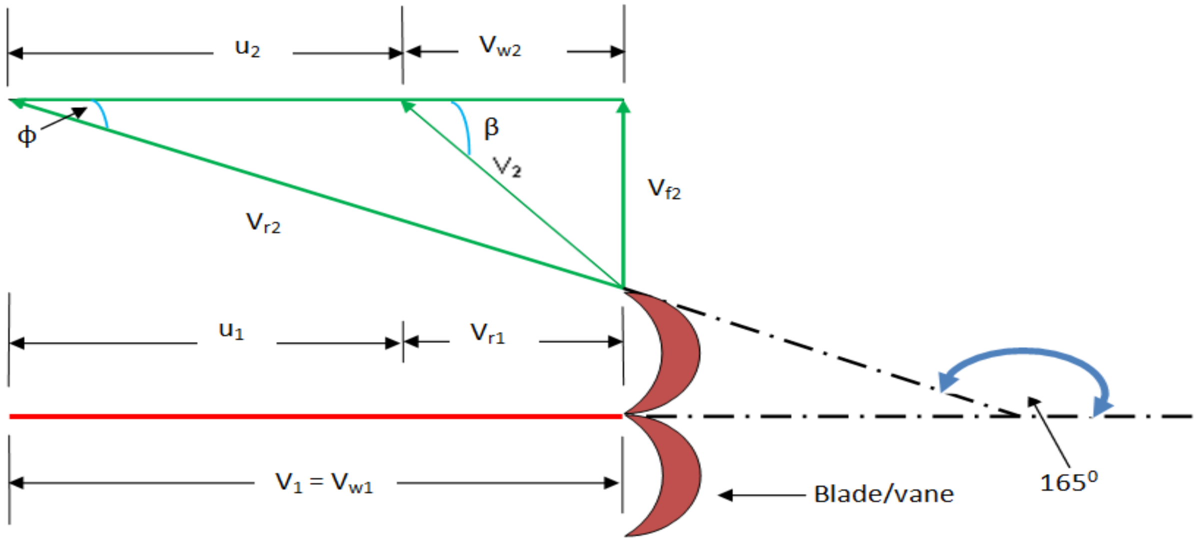

Figure 4.5: Velocity triangle diagram for the analysis of the performance of the Tablespoon Buckets Impulse Turbine

Vane angle at outlet $\phi = 180 - 165 = 15^0$

Co-efficient of velocity, $C_v = 1.0$

Speed ratio, $k_u = 0.45$

Density of water = 1000 kg/m^3

$$Velocity of jet at inlet: V_{jet} = C_v x\left(\sqrt{2\,gH}\right)$$

$$V_{jet} = 1.0\,x\left(\sqrt{2\,x\,9.81\,x\,35}\right) = 26.2\,m/s$$

$$Velocity of wheel: U = k_U x\left(\sqrt{2\,gH}\right)$$

Where k_u= speed ratio given as 0.45

$$U = 0.45\,x\left(\sqrt{2\,x\,9.81\,x\,35}\right) = 11.8\,m/s$$

From; V = velocity of jet = 26.2m/s,

U = velocity of wheel = 11.8m/s

Considering the velocity triangleshown as Figure 4.5,

$$V_{r1} = V_1 - u_1 = V_1 - u (but u_1 = u)$$

$$V_{r1} = 26.2 - 11.8 = 14.40\,m/s$$

$$Also, \quad V_{w1} = V_1 = 26.2\,m/s$$

From outlet velocity triangle

$$V_{r2} = V_{r1} = 14.40\,m/s$$

$$but, \quad V_{r2}\ Cos\phi = u_2 + V_{w2} = u + V_{w2}$$

$$then, \quad V_{w2} = V_{r2}\ Cos\phi - u$$

$$hence, \quad V_{w2} = 14.40\ Cos 15^0 - 11.8 = 2.11\,m/s$$

Work done by the jet on the runner per second is given as,

$$W = \rho Q (V_{w1} + V_{w2}) x u$$

$$W = 1000\,x\,0.0001433\,x(26.2 + 2.11)x\,11.8 = 47.87\,Nm/s$$

$$\therefore Power given by water to the runner = 47.87\,J/s$$

$$or Power (P) = 47.87\,W = 0.04787\,kW$$

4.2.4Hydraulic Efficiency

According to Rajput (2008), the hydraulic efficiency **(η_h)** is given as:

$$\eta_h = \frac{2\,(V-u)(1+kCOS\emptyset)u}{V^2}$$

Where K = blade friction co-efficient, which is slightly less unity. When bucket surfaces are perfectly smooth, energy losses due to impact at splitter are neglected and no friction, then k is assumed to be 1, Rajput (2008)

Since the bucket is not semi-circular, the blade angle was measured to be 165^o

Blade angle ($\emptyset$) = 165^o

Therefore; ϕ =180^o ─165^o = 15^o(Vane angle at outlet)

The following design parameters of the Pelton wheel are employed in this analysis:

Diameter of wheel, D =0.17m

Diameter of jet, d =0.03m

The vane angle of at outlet ϕ =15^o

Manufacturer's designed pump head = 35m

$$Velocity of jet at inlet: V_{jet} = C_v x\left(\sqrt{2\,gH}\right)$$

$$V_{jet} = 1.0\,x\left(\sqrt{2\,x\,9.81\,x\,35}\right) = 26.2\,m/s$$

$$Velocity of wheel: U = k_U x\left(\sqrt{2\,gH}\right)$$

Where k_u= speed ratio given as 0.45

$$U = 0.45\,x\left(\sqrt{2\,x\,9.81\,x\,35}\right) = 11.8\,m/s$$

From; V = velocity of jet = 26.2m/s,

U = velocity of wheel = 11.8m/s

Assuming K=1

$$\eta_h = \frac{2\,x(26.2 - 11.8)x(1 + COS 15^0)x\,11.8}{26.2^2} = 0.973 = 97.3\%$$

Alternatively:

$$\eta_h = \frac{2\,x(V_{w1} + V_{w2})xu}{V_1^2}$$

$$\eta_h = \frac{2\,x(26.2 + 2.11)x\,11.8}{26^2} = 0.9732 = 97.3\ \%$$

Or,

$$\eta_h = \frac{(V_{w1} + V_{w2})xu}{gH}$$

$$\eta_h = \frac{(26.2 + \ 2.11)x\ 11.8}{9.81\ x\ 35} \ = \ 0.9729 = \ 97.3\ \%$$

The result of the hydraulic efficiency of the Tablespoon buckets impulse turbine is in good agreement with the hydraulic efficiency result of Rajput (2008) standard experiment havingan angle of deflection of the jet of165^0, blade friction co-efficient K=1, co-efficient of velocityC_v = 1.0 and a speed ration of 0.45.

V. CONCLUSION

The TablespoonBucketsImpulse turbine, which is a small version is suitable for small hydroelectric power plants in case of high head and the low water flow rate was produced. The performance was analysis to confirm its workability. This hydraulic turbine operates, at no extra fuel consumption and with longer life span. It is an ecologically friendly machine and system. It will be appreciated by every individual, especially those running small scale enterprises and other small households. It is a way of utilizing the abundant water to generate wealth in electrical energy supply. This design can be adopted and applied to rural areas, since small rivers and streams exist within rural areas in Nigeria, most of which maintain a minimum flow all year round. The analysis of the micro hydro-power generation system shows that adjusting the valve position outward increases the discharge from the turbine, which correspondingly increases the power, hence the efficiency.This Tablespoon Buckets Pelton wheel has a hydraulic efficiency of 97.3% and is capable of producing 47.87W or 0.48 kW of power. The hydraulic efficiency of the Tablespoon Buckets Impulse turbine is in good agreement with Rajput (2008) standard experiment with the same angle of deflection of the jet of 165^0, blade friction co-efficient 1, co-efficient of velocity C_v = 1.0 and a speed ratio of 0.45. To enhance the power output, a higher capacity of the components of the turbine such as the dynamo can be used and the pump capacity increased.

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