Journal of Information Engineering and Applications
ISSN 2224-5782 (print) ISSN 2225-0506 (online)
Vol.4, No.10, 2014

Experimental Investigation on Effect of Head and Bucket Splitter Angle on the Power Output of A Pelton Turbine

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Abstract

This paper investigates through experiment, the effect of head and bucket splitter angle on the power output of a pelton turbine (water turbine), to improve the power generation by the use of efficient Hydro-electric power generation systems. Experiments were conducted on pelton turbine head conditions, high head and low flow with increased pressure delivered more energy on the bucket splitter which then generates a force in driving the wheel compared to the result obtained from low head and high flow operating conditions. The power output was maximum at 23^o splitter angle followed by 21^o, 15^o, 10^o and 3^o using varied turbine speed (1700, 1400, 1200 and 1000rpm). The force generated by the bucket due to the splitter was increased as the turbine speed was increasing. The force generated by the bucket was increased (0 to 0.38N) due to the energy delivered to the wheel by the head, the turbine output increases from (0 to 7.47kW) which influences the output. This increase in the power output was as a result of their head conditions and the bucket splitter angle.

1. INTRODUCTION

Electricity plays a very important role in the socio-economic and technological development of every nation. The electricity demand in Nigeria far outstrips the supply and the supply is epileptic in nature. The country is faced with acute electricity problems, which is hindering its development, notwithstanding the availability of vast natural resources in the country. It is widely accepted that there is a strong correlation between socio-economic development and the availability of electricity. There is a huge energy resource potential in Nigeria, which, if utilized, could minimize the present energy crisis prevailing in the country and enhance the process of rural electrification. The total exploitable renewable energy that can be derived annually from primary solar radiation, wind, forest biomass, hydropower, animal waste, crop residue and human waste is about 1,959x10^3 Tcal per year [1, 2]. Out of this, the share of hydro power is about 53.08 percent. Recently the country is involved in NIPP (National Integrated Power Projects) which are mainly gas turbine power generation projects. This work therefore sets out to complement the Gas Turbine sector in boosting the power generation of the country by use of efficient Hydro – electric power generating systems.

According to Newman [3], over 1.7billion people worldwide do not have access to electricity. This lack of electricity usually indicates low levels of infrastructure, development, education, health and quality of life. Using Nigeria as a point of reference in Africa where about half a million people lack access to electricity, even the power produced from Kanji dam and other dams are limited compared to the demand for power in the country. To make up for lack of electricity and to cope with increasing energy demands, so called traditional fuel use is high. This includes primarily the use of wood, charcoal, animal waste and other biomass. Over half a million people in Nigeria rely on traditional biomass fuels, with the highest rates of traditional fuel use correlating with areas of lowest access to electricity. The high use of biomass fuels has many negative environmental, social and health consequences. The demand for biomass generally leads to deforestation that in turn can causes soil erosion, habitat loss and desertification among other things. These biomass fuels are generally burned in inefficient stoves or lamps releasing soot into the atmosphere and leading to poor indoor air quality. Indoor air pollution accounts for 2.7% of all global disease [3, 4]. Due to their inherent low useful energy conversion efficiencies, high demand and dwindling supply, they are fast becoming the most expensive items for impoverished rural populations. In some cases, fuel accounts for 20 – 30% of total household income. To attain the level of power supply which the country requires, our dams have to be optimized by introducing pelton turbines for power generation schemes, in addition to improving and upgrading the available sources of energy in the country.

The work investigated through experimentation, the effect of head and bucket splitter angle on power output of a pelton turbine. The power output of a pelton turbine was equally investigated and a tachometer was used to check the speed of the shaft thereby determining the flow rate from the nozzle and how much energy is delivered by the pump to the wheel. The methodology involves a mathematical equation for hydraulic power delivered by the jet of water to the wheel at varied head which influences the turbine power output. Experiment and simulation were carried out to estimate the head conditions for a pelton turbine.

2. METHOD AND ANALYSIS

2.1. Experiment on Pelton Turbine

Fig.1 shows the arrangement, in which water is supplied from the reservoir, fed to a vertical pipe terminating in a tapered nozzle, pump is installed along the pipeline to boost the flow, pressure gauge is installed after the pump to determine the water pressure leaving the pump and a flow meter installed after the pump to determine the volumetric flow rate coming from the pump before reaching the nozzle. A bucket is attached at the periphery of the wheel which the jet of water strikes, thereby causing the rotary motion of the wheel which influences the power output of the turbine positively or negatively. A pulley is connected at the shaft with a belt to transmit the power to another pulley connected at the generator, causing the rotary motion of the shaft of the generator, thereby generating electricity. The valve is fully on, before the flow is allowed through the pump to the nozzle, as the flow process starts a tachometer is placed at the shaft to check the speed of the rotating shaft. After the reading must have been taken the valve is adjusted before taking another reading. This adjustment is made for about 4 to 5 trials. From the result obtained, the velocity of jet discharging through the nozzle to the bucket, the flow rate through the nozzle and the energy delivered to the wheel by the pump can be determined. The pump speed is kept constant all through the experiment, only the valve is adjusted.

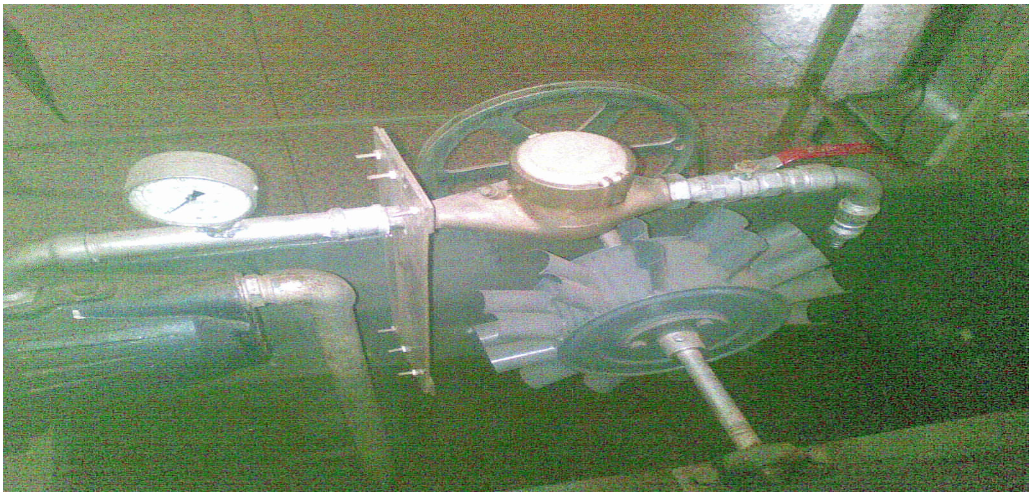

Fig.1: Pelton wheel in the Laboratory

2.2. Experiment Theory and Basic Equations

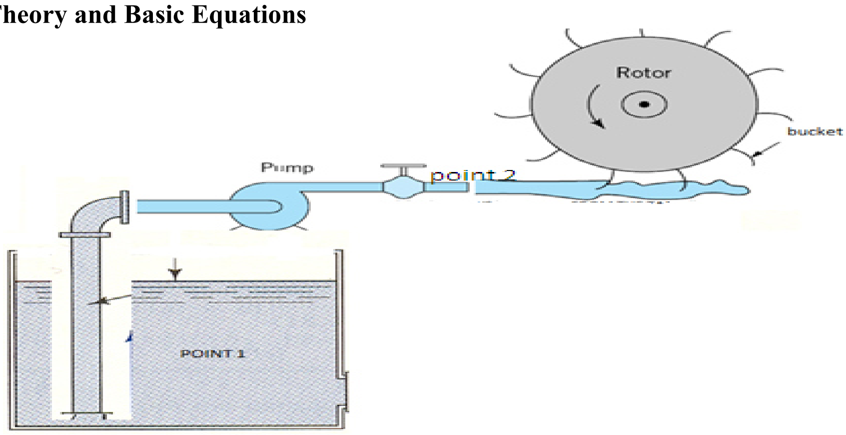

Fig.2: Flow from reservoir to wheel

It is necessary to establish the equation of flow process in fig.2 [5] in order to determine V_1 striking on the bucket surface which influences the power delivered to the wheel. The Bernoulli's equation is used to link the flow from point 1 to point 2.

$$E_1 = z_R + \frac{v^2{}_R}{2g} + \frac{p_R}{\rho g} \quad (1)$$

$$E_2 = z_n + \frac{v^2{}_n}{2g} + \frac{p_n}{\rho g} \quad (2)$$

Using the principle of conservation of energy;

$$E_1 + h_A = E_2 - h_R + h_l[6] \quad (3)$$

Therefore; $$\frac{p_n - p_R}{\rho g} + \frac{v^2{}_n - v^2{}_R}{2g} + z_n - z_R - h_R - h_l[6] \quad (4)$$

From the fig.2, at the surface of the reservoir 1, the fluid moves very slowly compared to the pipe, so we can say U_R = 0, Also the pressure is atmospheric pressure $p_R = p_{atmospheric}$. $z_n - z_R$ is the elevation from the nozzle to the water level in the reservoir, neglecting the minor and frictional losses. h_R, h_l = 0

2.3. The Energy Delivered to the Fluid by the Pump

Reducing Eq.4 to; $$h_A = \frac{v^2{}_n}{2g} + z_n - z_R[6] \quad (5)$$

For $\frac{v^2{}_n}{2g} = v_n$ is the velocity of the jet through the nozzle and can be determined from Eq.5, substituting values obtained during the experiment in the laboratory. The flow rate Q was determined based on the valve adjustment (for about 4 to 5 trials).

$$Q = v_n \text{ x } A_n \quad (6)$$

h_f = f L/D x $\frac{v^2{}_n}{2g}$ Church Chills' [7] frictional factor equation.

The Power Required in Driving the Wheel; $P = \rho$ x g x Q $x\ h_A$ (7)

The turbine peripheral velocity will be half the water jet velocity, $U_{turbine}$ = ½ x V_n

In metric form; 0.5 X V_n (m/s) = 5.235 x 10^{-5}x $\omega_{turbine}$(rpm) x $d_{turbine}$(mm)

Therefore the rotational velocity of the turbine is;

$$\omega_{turbine} = 0.5 \text{ x } 1.91 \text{ x } 10^4 \text{ x } \frac{V_n(\frac{m}{s})}{d_{turbine}(mm)} \quad (8)$$

$$V_n = 5.235 \text{ x } 10^{-5} \text{x } \omega_{turbine}(rpm) \frac{d_{turbine}(mm)}{2} \quad (9)$$

Shaft Power Output; $\dot{W}_{shaft} = \rho$ Q U (U - V_1) (1 - cosβ_1) (10)

Applying Eqs.(7 to 10) to the value obtained during the experiment and plotting the necessary graphs involved. The values obtained during the experiment are presented in table 1.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Data collected during the experiment: Nozzle size = 8mm, Elevation =0.6096m, Wheel = 220.98mm.

Table 1: Values obtained when the speed of turbine was 1700rpm

β_1(°)	Speed rpm	V_n (m/s)	Q (m^3/s)	h_A(J)	F_b (N)	P_w(kW)
3	1700	9.83	0.00049	5.53	0.0048	0.094
10	1700	9.83	0.00049	5.53	0.0072	1.42
15	1700	9.83	0.00049	5.53	0.16	3.15
21	1700	9.83	0.00049	5.53	0.32	6.29
25	1700	9.83	0.00049	5.53	0.38	7.47

Table 2: Values obtained when the speed of turbine was 1400rpm

β_1[°]	Speed rpm	V_n (m/s)	Q (m^3/s)	h_A (J)	F_b (N)	P_w(kW)
3	1400	8.09	0.00015	3.95	0.0039	0.047
10	1400	8.09	0.00015	3.95	0.059	0.705
15	1400	8.09	0.00015	3.95	0.134	1.59
21	1400	8.09	0.00015	3.95	0.26	3.05
25	1400	8.09	0.00015	3.95	0.31	

Table 3: Values obtained when the speed of turbine was 1200rpm

β_1[°]	Speed rpm	V_n (m/s)	Q (m^3/s)	h_A(J)	F_b (N)	P_w(kW)
3	1200	6.94	0.00012	3.06	0.0034	0.047
10	1200	6.94	0.00012	3.06	0.051	0.705
15	1200	6.94	0.00012	3.06	0.12	1.59
21	1200	6.94	0.00012	3.06	0.22	3.05
25	1200	6.94	0.00012	3.06	0.27	3.75

Table 4: Values obtained when the speed of turbine was 1000rpm

β_1[°]	Speed rpm	V_n (m/s)	Q (m^3/s)	h_A(J)	F_b (N)	P_w(kW)
3	1000	5.78	0.00012	2.31	0.028	0.33
10	1000	5.78	0.00012	2.31	0.042	0.49
15	1000	5.78	0.00012	2.31	0.096	1.11
21	1000	5.78	0.00012	2.31	0.19	2.14
25	1000	5.78	0.00012	2.31	0.22	2.57

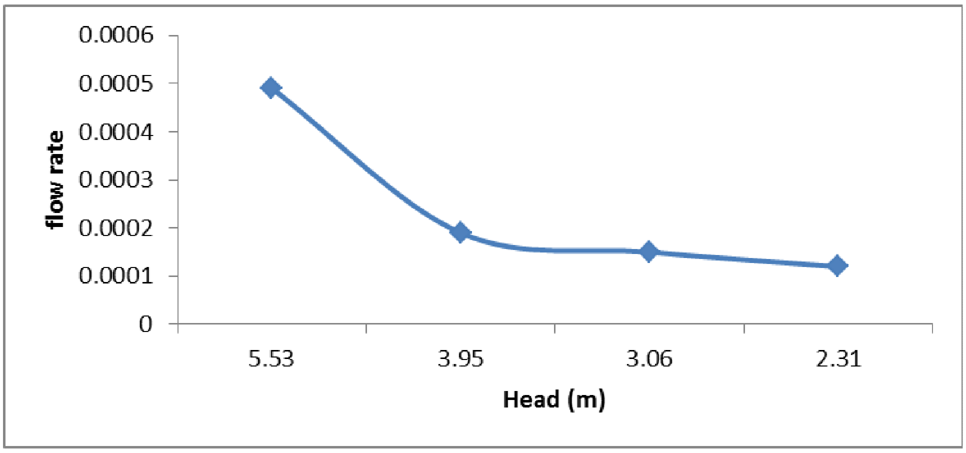

Fig.3: Shows Head Vs volumetric flow rate

Using the valve to control the energy delivered by the fluid to the wheel, the valve was adjusted from minimum to maximum setting, the volumetric flow rate through the nozzle was increasing (0 to 0.0005m^3/s)as the energy delivered by the head to the wheel was increasing from (0 to 5.3). As a result of this increase the turbine speed and the power output was influenced positively.

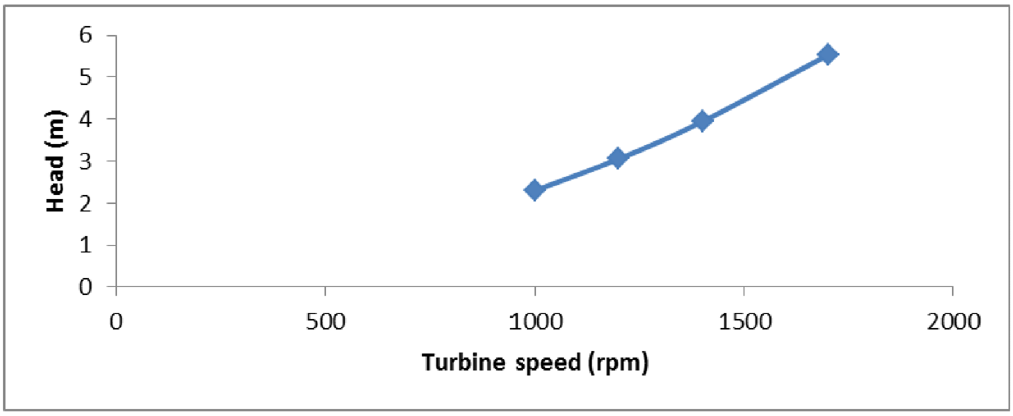

Fig.4: Head Vs Turbine speed

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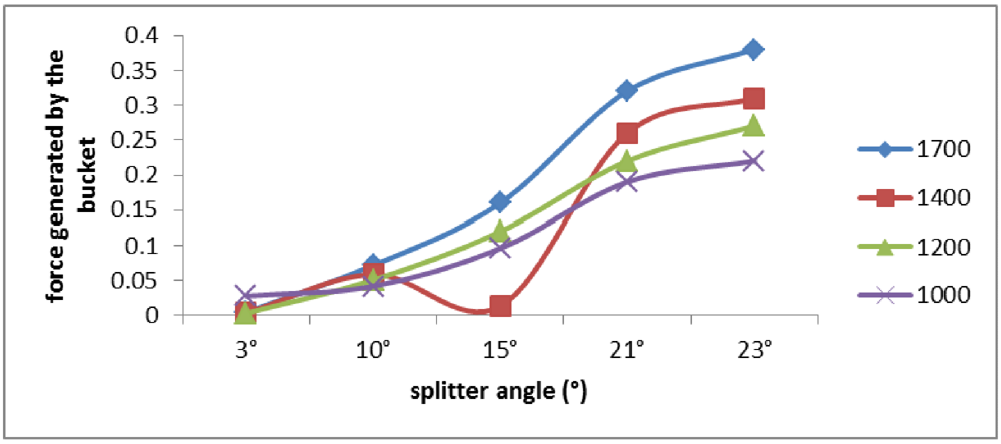

Fig.5: Force generated by the bucket Vs splitter angle at different turbine speeds

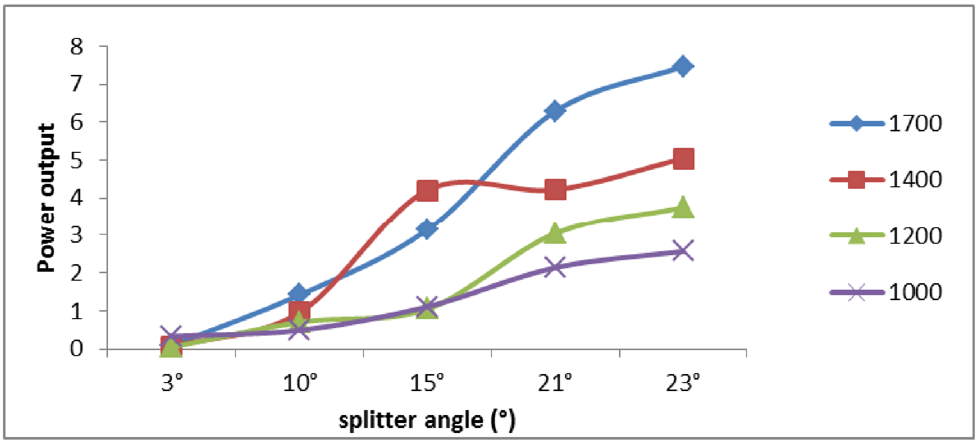

Fig.6: power output Vs splitter angle at different turbine speeds

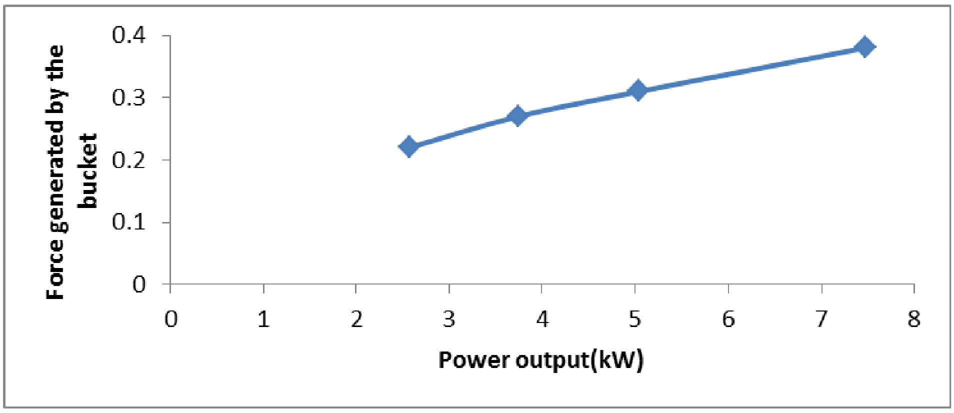

Fig.7: Force generated by the bucket Vs power output.

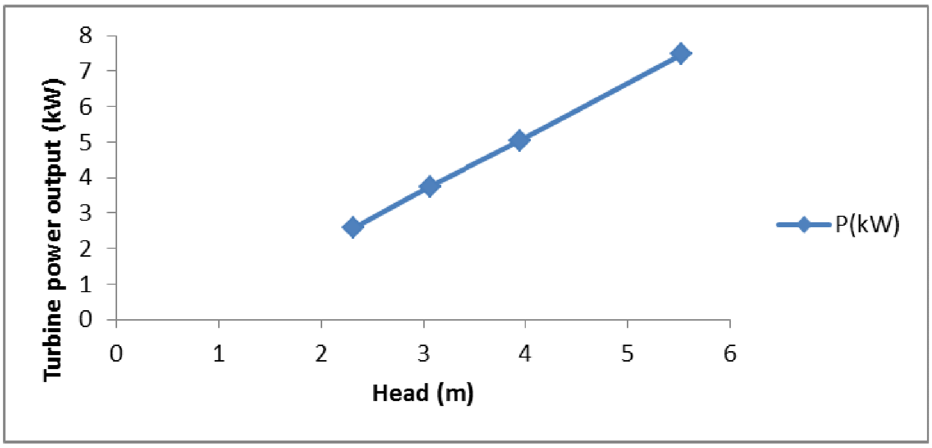

Fig.8: Turbine power output Vs Head

From Fig.4, as the head was increasing (2.31 to 5.53), the turbine speed was influenced (1000 to 1700rpm). This influence increases the system power output.

From Fig.5, the force generated by the bucket was maximum at 23° splitter angle (0.38N, 0.31N, 0.027N and 0.22N) at a turbine speed of 1700rpm followed by 21° splitter angle (0.032N, 0.026N, 0.022N and 0.019N) at a turbine speed of 1400rpm. At 15° splitter angle the force generated was (0.16N, 0.134N, 0.12N and 0.096N) at a turbine speed of 1200rpm and other splitter angles are 10° (0.072N, 0.059N, 0.051Nand 0.042N) and 3° (0.0048N, 0.0039N, 0.0034N, 0.024N). The force generated by the bucket due to the splitter was increased as the turbine speed was increasing.

From Fig.6, the power output was maximum at 23° splitter angle followed by 21°, 15°, 10° and 3° using varied turbine speed (1700, 1400, 1200 and 1000rpm).
From Fig.7 and Fig.8, as the force generated by the bucket was increased (0 to 0.38N) due to the energy delivered to the wheel by the head, the turbine power output increased from (0 to 7.47kW) which influenced the output. This increase in the power output was as a result of head and the bucket splitter.

4. CONCLUSION

Experiment was conducted on a pelton turbine to determine the power output, using a tachometer to check the speed at which the turbine was operating. During the experiment the head was low; the reason for the low head was as a result of the pump operating at a constant speed. The flow pressure was slightly influenced as the valve was adjusted. The flow through the nozzle was influenced while the pressure at which the jet strikes the bucket changed slightly but not enough to generate much energy on the wheel. As the valve was adjusted from minimum to maximum setting, the flow rate through the nozzle was increased after each adjustment thereby increasing the force generated by the bucket as the jet strikes the splitter.

From the graph obtained, as the force generated by the bucket was increased (0 to 0.38N) due to the energy delivered to the wheel by the head, the turbine power output increased from (0 to 7.47kW) which influenced the output. This increase in the power output was as a result of head condition and the bucket splitter. Alternator was used as the generator for the conversion of mechanical energy to electrical energy on the system. A 60watt bulb was connected at the output of the alternator terminals, as the flow was increasing by adjusting the valve the 60watt bulb lit up. The power output from the alternator is based on the system configuration from the manufacturer, each generator has a specific speed at which the turbine should be running in order to meet the required output and also the conversion of energy in the system. According to some researchers [8, 9] and observation made during the experiment, the following conclusions can be reached; the pelton turbine operating on high head and low flow with increased pressure condition generated a power output which could be applied in siting a large hydro power plant while that of the low head and high flow with decreased pressure generated a lesser output and could be applied in siting a small MHPP.

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