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# Optimization of the Operational Conditions for Low-Head Pelton Wheel Turbine Developed for Power Generation

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***Author's contribution***

*The sole author designed, analyzed and interpreted and prepared the manuscript.*

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## ABSTRACT

In a bid to optimize the performance of a Pelton Wheel Turbine developed the performance evaluation of the turbine at various conditions was carried out using a portion of the overflow from the University of Ilorin (UNILORIN) dam. The collected overflow has a net head of 4 m, flow rate of 0.017m$^3$/sec. and theoretical hydropower energy of 668W. The turbine was tested and the optimized value of operating conditions namely; angle of inclination (15$^o$ above tangent, tangential and 15$^o$ below tangent), height to impact point (200 mm, 250 mm and 300 mm) and length to impact point (50 mm, 100 mm and 150 mm) were pre-set at their various levels. The measured outputs were Turbine Speed, Turbine Torque, Alternator Speed as well as the output voltage. The optimum values of the process output or measured parameters were determined statistically using a 3$^3$X2 factorial experiment in three replicates. The optimum Turbine speed (538.38 rpm) in off load condition was achieved at 250 mm height to impact point, 150 mm length to impact point and angle at tangential inclination. Similar combination also yielded an optimum turbine torque of 46.16 kNm. The optimum Turbine speed (392.02 rpm) in on-load condition was achieved at 250 mm height to impact point, 150 mm length to impact point and angle at tangential inclination. Similar combination also yielded an optimum Turbine Torque of 36.46kNm, optimum Alternator speed of 1768.56 rpm

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and an optimum output voltage of 7.87V. The results therefore show that the turbine must be set at 250 mm height to impact point, 150 mm length to impact point and the water jet at a tangential flow for it to perform optimally.

*Keywords: Micro hydropower; pelton wheel turbine; optimization; power generation; dam overflow.*

## 1. INTRODUCTION

Hydropower plants makes use of the energy developed by moving water from sources such as the ocean, rivers and waterfalls to move vane-like blades in a turbine which turns a shaft connected to a generator. The generator has a powerful electromagnet (a rotor) which is turned inside a coil of copper bars (a starter). This produces an electromotive force or the process of exciting electrons to jump from atom to atom. When electrons flow along a wire or other conductor, jumping from atom to atom, they create an electric current or a flow of electricity. The first hydropower supply station in Nigeria is at Kainji on the river Niger where the installed capacity is 836 MW with provisions for expansion to 1156 MW. A second hydropower station on the Niger is at Jebba with an installed capacity of 540 MW. An estimate by Aliyu and Elegba [1] for rivers Kaduna, Benue and Cross River (at Shiroro, Makurdi and Ikom, respectively) put their total capacity at about 4,650 MW. Estimates for the rivers on the Mambila Plateau are put at 2,330MW. The foregoing assessment is for large hydro schemes which have predominantly been the class of schemes in use prior to the oil crisis of 1973. Since that time, however, many developed and developing countries have opted for small scale hydropower with appreciable savings made over the otherwise alternative to crude oil. It should be noted that hydropower plants that supply electrical energy between the range of 15 kW to 15MW are mini-hydro while those supplying below 15kW are normally referred to as micro-hydro plants [2]. Indeed, small scale (both micro and mini) hydropower systems possess so many advantages over large hydro systems, which includes ease of setting up, low maintenance requirement, less skilled operators required and the problems of topography is minimal. In effect, small hydropower systems can be set up in all parts of the country so that the potential energy in the large network of rivers can be tapped and converted to electrical energy. In this way the nation's rural electrification projects can be greatly enhanced. Hydropower has been regarded as the ideal fuel for electricity generation because, unlike the non-renewable fuels used to generate electricity, it is almost free, there are no waste products, and hydropower does not pollute the water or the air. However, it is criticized because it does change the environment by affecting natural habitats and large hydropower schemes have been seen as a weapon of mass destruction in case of failure or attack during war. Furthermore, the estimated long-term power demand of Nigeria was 25 GW for the year 2010 to sustain industrial growth [3]. The Power Holding Company of Nigeria (PHCN, as it was then called) has an installed capacity of only 6 GW, out of which less than 2.5GW is the actual available output. Of this, thermal plants provide 61%, while hydropower generation is about 31% [4]. Developing micro hydropower could therefore be a solution to the inadequate power supply from the national grid especially to rural areas. It can as well be a key driver in rural development programs. Recently, a lot of researchers have developed several Pelton Wheels, a compilation is shown in Table 1.

Due to the expected limitations pertaining publication of results concerning turbines from commercial companies, one of the goals of this research paper was to establish optimized conditions for running a Pelton wheel turbine because even though this is a well-established turbine technology, there are still so many unanswered questions regarding design and optimization especially when used at low heads. Also, this research aims to compare the optimized output with the references from Table 1. Even though, some of the results in

**Table 1. Some Pelton turbine studies and a few of the outputs**

| Investigator | Flow rate ($m^3$/Sec) | Net head (m) | Runner speed (rpm) |
|---|---|---|---|
| Panagiotopoulos et al. [5] | - | 100 | 1000 |
| Panthee et al. [6] | 0.05 | 53.9 | 600 |
| Pudasaini et al. [7] | 0.09218 | 80.85 | 600 |
| Solemslie and Dahlhaug [8] | - | 70 | - |

Table 1 may have also depended on the laboratory settings and other controls of design parameters; the results still indicate room for further performance improvement. Thus, further development is still relevant today. Furthermore, according to Tilahun [9], a design and optimization studies that evaluates and establish the links between the size of the runner and the flow field characteristics is needed.

## 2. MATERIALS AND METHODS

### 2.1 The University of Ilorin (Unilorin) Dam

Fig. 1 shows the pictorial view of the University of Ilorin (UNILORIN) dam. it was commissioned in 2007 primarily for water supply; it is located on the Oyun River. The Dam is a zoned earth fill embankment with an ogee-shaped concrete spillway. The intake for water supply and the low lift pumping station are located on the wing wall. According to Oyebode [10], the dam Overflow has a net head of 4m, a flow rate of 1.7 x $10^{-2}$ $m^3s^{-1}$ approximately 667W theoretically available hydropower.

**Fig. 1. Pictorial View of Unilorin Dam**
*Source: [11]*

### 2.2 The Pelton Wheel Turbine Used

Table 2 is a summary of the specifications of the Pelton wheel, head of water (h), discharge (q) and the theoretically available hydropower from the portion of the dam overflow used for the experiment.

#### 2.2.1 Other components of the hydropower generator

The nozzle is made up of a galvanized steel pipe with an inlet radius of 100 mm and an outlet radius of 50 mm. It receives the flowing water and discharges it at a higher velocity to the turbine. It has been designed in a way that allows it to be raise upward and downward, it could also be moved forwards and backwards towards the Pelton wheel cup, it can as well be inclined at varying inclination. The alternator used was a second hand 12V diesel engine alternator. A survey of similar brands revealed that the alternators are rated 650 watts and run between 1000 and 1500 rpm.

### 2.3 Experimental Factors and Statistical Analysis

The operating conditions manipulated were angle of inclination of the water jet (15º above tangent, tangential, and 15º below tangent), Height of the water jet to Impact Point (200mm, 250mm and 300mm), and Length of the water jet to impact point (50mm, 100mm and 150mm). The effect of these process parameters on the various outputs were investigated under two different conditions (off-load and on-load). The off-load implies that the turbine was left to run without attaching the alternator while the on-load condition implies that the alternator had been connected to the Turbine by means of a belt and pulley system. The pulley system was designed to deliver the rotational speed at the rate of 1:6.

The performance of the turbine was evaluated using a $3^3$X2 (three factors and three levels under two conditions) factorial experimental design. Table 3 shows the factorial experimental design layout used.

### 2.4 Measured Parameters

#### 2.4.1 Speed

The speed was measured using a tachometer. The nob of the tachometer was placed at the punched center of the shaft and the readings were recorded. The Tachometer used was a contact type and it was manufactured by Fisons. The model is TAF – 420 – K and it has a capacity of 100,000 rpm.

#### 2.4.2 Output voltage

The output voltage was measured using a D.C. Multimeter. It was manufactured by Fison. The model is DT9205M and it has a capacity of 1000V.

#### 2.4.3 Torque

The turbine torque was measured using a hand-held Shimpo FG-7000T-3 Digital Torque Meter.

**Table 2. Summary table for pelton wheel turbine**

| S/N | Parameter | Dimension |
|---|---|---|
| 1. | Hydraulic Head ($H_n$) | 4.0m |
| 2. | Flow Rate (q) | 1.7 X $10^{-2}$ $m^3s^{-1}$ |
| 3. | Available Power | 667 Watts |
| 4. | Rotational Speed (rpm) | 1500 rpm |
| 5. | Absolute Velocity of Water Jet ($c_1$) | 8.50 m/s |
| 6. | Optimal Jet Diameter (d) | 51mm |
| 7. | Optimal Peripheral Velocity | 4.0m/s |
| 8. | Pitch Circle Diameter (D) | 0.26m |
| 9. | Bucket Width (b) | 163.2mm |
| 10. | Bucket height (h) | 137.7mm |
| 11. | Cavity Length ($h_1$) | 17.5mm |
| 12. | Length to Impact Point ($h_2$) | 76.5mm |
| 13. | Bucket depth (t) | 45.9mm |
| 14. | Cavity Width (a) | 61.2mm |
| 15. | Offset of Bucket (k) | 8.7mm |

*Source: [12]*

**Fig. 2. Pictorial view of the pelton wheel turbine**

**Table 3. Design layout for treatment combination**

| S/N | Factors | Levels | | |
|---|---|---|---|---|
| 1 | H (mm) | 200 | 250 | 300 |
| 2 | V (mm) | 50 | 100 | 150 |
| 3 | I | 15º above tangent | Tangential | 15º below tangent |
| 4 | C | Off-load | On-Load | |

*Key H - Height of water jet to impact point, V - Length of water jet to impact point, I - Inclination of water jet to impact point, C - Condition of the Turbine*

## 3. RESULTS AND DISCUSSION

### 3.1 Descriptive Statistics

Table 4 shows the summary statistics of the data collected during the Experiment. It can be inferred from the table that the mean values of Turbine speed vary depending on the operation parameters being employed. Variations in Turbines speed also occurred along the levels of operation parameter. Similar pattern was observed for all other output namely, Turbine Torque, Alternator Speed and Output voltage. These may suggest that process parameter manipulated does not have same effect on the output/responses.

## 3.2 Effect of Operation Parameters on Turbine Speed and Turbine Torque for Off-load Condition

### 3.2.1 Turbine speed

Table 5 shows the effect of angle of inclination, height to impact point and length to impact point pre-set at various levels on Turbine speed under Off-load condition. The results show that the pre-set levels of the three process parameters was statistically significant at 5% level. The hypothesis of equal Turbine Speed irrespective of the operation parameters was therefore rejected. This means that variations observed in Turbine Speed as recorded in Table 4 were due to effect of the operation parameters and not by chance occurrence.

To determine the differences in the angle of inclination, height to impact point and length to impact point on mean effect of Turbine Speed, New Duncan's Multiple Range Test (DMRT) was conducted (Table 6). The result of the comparison of Turbine Speed among the three levels of angle of inclination (15º above, tangential and 15 º below) revealed that the observed means of Turbine Speed are significantly different from one level to the other. Turbine Speed observed at tangential level (470.33rpm) was significantly higher than Turbine speed observed at 15º above and 15º below tangent respectively. Turbine Speed observed at 15º above tangent (411.48rpm) was significantly higher than Turbine Speed recorded at 15º below tangent (403.33rpm). At 300mm height to impact point, a Turbine speed of 477.44rpm was observed and this was significantly higher than the Turbine speed observed at 250 mm and 200 mm respectively. Turbine speed observed at the later levels (250 mm and 200 mm) are the same on the average. A higher Turbine speed of 466.74 rpm was observed at 100 mm Length to Impact Point. This value was significantly higher than Turbine speed observed at 150 mm and 50 mm respectively.

**Table 4. Descriptive statistics of speed of turbine and torque using the various operation parameter**

| Operation parameter | Level | Turbine speed | | Turbine torque | | Alternator speed | | Output voltage | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Condition | Off Load | 428.38 | 55.54 | 36.73 | 4.76 | | | | |
| | On Load | 301.28 | 38.88 | 28.00 | 3.63 | | | | |
| Inclination (I) | 15º above | 350.31 | 77.65 | 31.08 | 5.94 | 1304.07 | 173.73 | 6.02 | 0.80 |
| | Tangential | 400.57 | 76.36 | 35.54 | 5.49 | 1490.44 | 108.63 | 6.88 | 0.50 |
| | 15º below | 343.61 | 73.80 | 30.48 | 5.59 | 1283.19 | 154.74 | 5.92 | 0.72 |
| Height to Impact Point (V) | 200mm | 345.89 | 72.81 | 30.69 | 5.50 | 1292.74 | 151.44 | 5.97 | 0.70 |
| | 250mm | 342.20 | 73.91 | 30.36 | 5.60 | 1275.26 | 156.81 | 5.89 | 0.72 |
| | 300mm | 406.41 | 76.62 | 36.05 | 5.47 | 1509.70 | 100.11 | 6.97 | 0.46 |
| Length to Impact Point (H) | 50mm | 345.85 | 75.71 | 30.67 | 5.76 | 1285.15 | 156.73 | 5.93 | 0.72 |
| | 100mm | 397.43 | 77.45 | 35.26 | 5.62 | 1484.96 | 119.06 | 6.85 | 0.55 |
| | 150mm | 351.22 | 76.90 | 31.16 | 5.88 | 1307.59 | 171.30 | 6.03 | 0.79 |

**Table 5. Effect of operation parameter on turbine speed in off-load condition**

| Source | Sum of squares | Df | Mean square | F | Sig |
|---|---|---|---|---|---|
| A | 72170.40 | 2 | 36085.20 | 876.43 | 0.001* |
| B | 97598.32 | 2 | 48799.16 | 1185.23 | 0.001* |
| C | 59878.54 | 2 | 29939.27 | 727.16 | 0.001* |
| A * B | 5762.20 | 4 | 1440.55 | 34.99 | 0.001* |
| A * C | 1549.53 | 4 | 387.38 | 9.41 | 0.001* |
| B* C | 3362.72 | 4 | 840.68 | 20.42 | 0.001* |
| A*B*C | 4258.10 | 8 | 532.26 | 12.93 | 0.001* |
| Error | 2223.33 | 54 | 41.17 | | |
| Total | 246803.14 | 80 | | | |

*A=Inclination, B=Height to Impact Point, C=Length to Impact Point, *=Significant @ 5%*

### 3.2.2 Turbine torque

The result of the effect of operation conditions on Turbine Torque is presented on Table 7. It can be observed that all the process conditions and their interactions had significant effect on Turbine Torque before load application at 5% level of significance. This implies that each operation conditions independently influenced Turbine Torque and also had combined effect on the Turbine Torque. It can therefore be concluded from the foregoing that at least one treatment effect is significantly different from the others. Table 8 shows the comparisons between the different levels of the process condition using the New Duncan Multiple Range Test (DMRT). In comparing the means of Turbine Torque at the three levels of angle of inclination considered in the study for the Pelton Wheel Turbine, it was observed that the highest mean Turbine Torque of 40.33 kNm was obtained at tangential level, while the lowest Turbine Torque of 34.58kNm and 35.29kNm were observed at 15º below and 15º above tangent respectively. Tangential level of angle of inclination had significantly higher Turbine Torque than both 15º below and 15º above tangent. A Turbine Torque of 40.93kNm was observed at 300 mm height to impact point which is significantly higher than Turbine Torque observed at 250mm (34.51kNm) and 200 mm (34.76kNm) respectively.

**Table 6. Comparing the mean values of turbine speed using duncan multiple range test**

| Factor | Level | Turbine speed |
|---|---|---|
| Inclination | 15º above | 411.48a |
| | Tangential | 470.33b |
| | 15º below | 403.33c |
| Height to Impact Point | 200mm | 405.30a |
| | 250mm | 402.41a |
| | 300mm | 477.44b |
| Length to Impact Point | 50mm | 406.89a |
| | 100mm | 466.74b |
| | 150mm | 411.52a |

*Means with the same alphabet are not significantly different from each other*

**Table 7. Effect of operation parameter on turbine torque in off-load condition**

| Source | Sum of squares | Df | Mean square | F | Sig |
|---|---|---|---|---|---|
| A | 530.85 | 2 | 265.42 | 854.84 | 0.001* |
| B | 713.20 | 2 | 356.60 | 1148.50 | 0.001* |
| C | 438.56 | 2 | 219.28 | 706.23 | 0.001* |
| A * B | 42.29 | 4 | 10.57 | 34.05 | 0.001* |
| A * C | 11.45 | 4 | 2.86 | 9.22 | 0.001* |
| B* C | 24.41 | 4 | 6.10 | 19.66 | 0.001* |
| A*B*C | 31.65 | 8 | 3.96 | 12.74 | 0.001* |
| Error | 16.77 | 54 | 0.31 | | |
| Total | 1809.18 | 80 | | | |

*A=Inclination, B=Height to Impact Point, C=Length to Impact Point, *=Significant @ 5%*

**Table 8. Comparing the mean values of turbine torque using Duncan multiple range test**

| Process parameter | Level | Turbine torque |
|---|---|---|
| Inclination | 15º above | 35.29a |
| | Tangential | 40.33b |
| | 15º below | 34.58a |
| Height to Impact point | 200mm | 34.76a |
| | 250mm | 34.51a |
| | 300mm | 40.93b |
| Length to Impact | 25mm | 34.89a |
| | 75mm | 40.01b |
| | 125mm | 35.29c |

*Means with the same alphabet are not significantly different from each other*

## 3.3 Effect of Operating Parameters on Process Output for On-load Condition

### 3.3.1 Turbine speed

Table 9 shows the effect of operating parameters on the turbine speed at on-load condition, it can be observed that angle of inclination, height to impact point and length to impact point had significant effect on Turbine Speed when the Turbine is on load at 5% level of significance. The interactions between these process parameters also had significant effect on Turbine Speed at 5% level of significance. This implies that at least one level of the process conditions manipulated is significantly different from the others. Table 10 compares the mean of Turbine speed along the levels of angle of inclination, height to impact point and length to impact point for both Turbines. For the Pelton Wheel Turbine, the tangential level of angle of inclination had a significantly higher Turbine speed of 330.81rpm compared to a Turbine speed of 289.15rpm and 283.89rpm observed at 15º above and 15º below tangent respectively.

A Turbine speed of 335.37rpm was observed at 300mm height to impact point. This value was statistically higher than those observed at 250mm and 200mm height to impact point respectively.

At 100mm length to impact point, highest Turbine speed (328.11rpm) was observed which thereafter decreases to 290.93rpm at 150mm length to impact point.

### 3.3.2 Turbine torque

Table 11 shows the effect of angle of inclination, height to impact point and length to impact point preset at various levels, on Turbine Torque at On-load condition. The results show that the preset levels of the three process parameters was statistically significant at 5% level. The hypothesis of equal Turbine Torque irrespective of the process parameters was therefore rejected. This means that variances earlier observed in Turbine Torque in Table 4 above were actually due to effect of the process parameters namely, angle of inclination, height to impact point and length to impact point.

Table 12 shows the comparisons between the different levels of angle of inclination, height to impact point and length to impact point using the New Duncan Multiple Range Test (DMRT). Table 12 shows that a mean Turbine Torque of about 30.76kNm was observed at the tangential angle of inclination. This value was significantly higher than Turbine Torque observed at 15º above and 15º below tangent respectively. Turbine Torque

**Table 9. Effect of operation parameter on turbine speed in on-load condition**

| Source | Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| A | 35692.32 | 2 | 17846.16 | 2144.72 | 0.001* |
| B | 47327.43 | 2 | 23663.72 | 2843.86 | 0.001* |
| C | 29651.88 | 2 | 14825.94 | 1781.75 | 0.001* |
| A * B | 3533.16 | 4 | 883.29 | 106.15 | 0.001* |
| A * C | 857.38 | 4 | 214.35 | 25.76 | 0.001* |
| B* C | 2023.16 | 4 | 505.79 | 60.79 | 0.001* |
| A*B*C | 1375.80 | 8 | 171.98 | 20.67 | 0.001* |
| Error | 449.33 | 54 | 8.32 | | |
| Total | 120910.47 | 80 | | | |

*A=Inclination, B=Height to Impact Point, C=Length to Impact Point, *=Significant @ 5%*

**Table 10. Comparing the mean values of turbine speed using duncan multiple range test**

| Factor | Level | Turbine Speed |
|---|---|---|
| Inclination | 15º above | 289.15a |
| | Tangential | 330.81b |
| | 15º below | 283.89c |
| Height to Impact | 200mm | 286.48a |
| | 250mm | 282.00b |
| | 300mm | 335.37c |
| Length to Impact | 50mm | 284.81a |
| | 100mm | 328.11b |
| | 150mm | 290.93c |

*Means with the same alphabet are not significantly different from each other*

**Table 11. Effect of operation parameter on turbine torque in on-load condition**

| Source | Sum of squares | Df | Mean square | F | Sig. |
|---|---|---|---|---|---|
| A | 310.85 | 2 | 155.42 | 2252.10 | 0.001* |
| B | 410.31 | 2 | 205.15 | 2972.72 | 0.001* |
| C | 259.89 | 2 | 129.94 | 1882.90 | 0.001* |
| A * B | 30.53 | 4 | 7.63 | 110.61 | 0.001* |
| A * C | 7.58 | 4 | 1.89 | 27.46 | 0.001* |
| B* C | 18.08 | 4 | 4.52 | 65.48 | 0.001* |
| A*B*C | 12.03 | 8 | 1.50 | 21.78 | 0.001* |
| Error | 3.73 | 54 | 0.07 | | |
| Total | 1052.98 | 80 | | | |

*A=Inclination, B=Height to Impact Point, C=Length to Impact Point, *=Significant @ 5%*

**Table 12. Comparing the mean values of turbine torque using duncan multiple range test**

| Factor | Level | Turbine Torque |
|---|---|---|
| Inclination | 15º above | 26.87a |
| | Tangential | 30.76b |
| | 15º below | 26.37a |
| Height to Impact | 200mm | 26.62a |
| | 250mm | 26.21b |
| | 300mm | 31.17c |
| Length to Impact | 50mm | 26.46a |
| | 100mm | 30.51b |
| | 150mm | 27.03c |

*Means with the same alphabet are not significantly different from each other*

observed at 15º above tangent (26.87kNm) was statistically the same on the average with Turbine Torque recorded at 15º below tangent (26.37kNm). At 300mm height to impact point, a Turbine Torque of 31.17kNm was observed and this was significantly higher than the Turbine Torque observed at 250mm and 200mm respectively. Turbine Torque observed at the later levels (250mm and 200mm) is the same on the average.

A higher Turbine Torque of 30.51kNm was observed at 100mm Length to Impact Point. This value was significantly higher than Turbine Torque observed at 150mm and 50mm respectively.

#### 3.3.3 Alternator speed

Table 13 shows the effect of process parameters (angle of inclination, height to impact point and length to impact point) on Alternator Speed. The results show that variations observed in Alternator speed were significantly due to process parameters manipulated during the evaluation. The hypothesis of equal mean values of Alternator speed across all levels of process parameters was therefore rejected. This means that variations observed in Alternator speed during the performance evaluation was due to effect of changes in the level of process parameter manipulated or preset.

Table 14 compares the mean of Alternator speed along the three levels of angle of inclination, height to impact point and length to impact point for both Alternators. For the Pelton Wheel Turbine, the tangential level of angle of inclination had a significantly higher Alternator speed of 1490.44 rpm compared to an alternator speed of 1304.07rpm and 1283.19rpm observed at 15º above and 15º below tangent respectively. An Alternator speed of 1509.70rpm was observed at 300mm height to impact point. This value was statistically higher than those observed at 250mm and 200mm height to impact point respectively. At 100mm length to impact point, higher Alternator speed (1484.96 rpm) was observed which thereafter decreases significantly to 1307.59rpm at 150mm height to impact point.

#### 3.3.4 Output voltage

Table 15 show that various process parameters examined had significant effect on the Output voltage of the two Turbines respectively at 5% level of significant. This implies that Output Voltage of the two turbines is dependent on at least one and /or all the process parameters preset at their various levels. It can therefore be safely concluded that all process parameters manipulated do not have the same effect on the output voltage of both Turbines under study.

Table 16 shows the comparisons between the different levels of angle of inclination, height to impact point and length to impact point using the New Duncan Multiple Range Test (DMRT). Table 15 shows that a mean output voltage of about 6.88V was observed at the tangential angle of inclination. This value was significantly higher than output voltage observed at 15º above and 15º below tangent respectively. Output voltage observed at 15º above tangent (6.02V) was statistically higher on the average compared to output voltage recorded at 15º below tangent (5.92V). At 300mm height to impact point, a mean output voltage of 6.97V was observed and

**Table 13. Effect of operation parameter on alternator speed in on-load condition**

| Source | Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| A | 703139.95 | 2 | 351569.98 | 10105.45 | 0.001* |
| B | 921084.54 | 2 | 460542.27 | 13237.73 | 0.001* |
| C | 647009.65 | 2 | 323504.83 | 9298.75 | 0.001* |
| A * B | 62815.60 | 4 | 15703.90 | 451.39 | 0.001* |
| A * C | 15585.16 | 4 | 3896.29 | 111.99 | 0.001* |
| B* C | 35467.23 | 4 | 8866.81 | 254.87 | 0.001* |
| A*B*C | 30269.73 | 8 | 3783.72 | 108.76 | 0.001* |
| Error | 1878.67 | 54 | 34.79 | | |
| Total | 2417250.54 | 80 | | | |

*A=Inclination, B=Height to Impact Point, C=Length to Impact Point, *=Significant @ 5%*

**Table 14. Comparing the mean values of alternator speed using duncan multiple range test**

| Factor | Level | Alternator speed |
|---|---|---|
| Inclination | 15º above | 1304.07a |
| | Tangential | 1490.44b |
| | 15º below | 1283.19c |
| Height to Impact | 200mm | 1292.74a |
| | 250mm | 1275.26b |
| | 300mm | 1509.70c |
| Length to Impact | 50mm | 1285.15a |
| | 100mm | 1484.96b |
| | 150mm | 1307.59c |

*Means with the same alphabet are not significantly different from each other*

**Table 15. Effect of operation parameter on output voltage in on-load condition**

| Source | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|
| A | 14.97 | 2 | 7.49 | 9257.69 | 0.001* |
| B | 19.61 | 2 | 9.81 | 12125.70 | 0.001* |
| C | 13.82 | 2 | 6.91 | 8542.61 | 0.001* |
| A * B | 1.35 | 4 | 0.34 | 416.80 | 0.001* |
| A * C | 0.34 | 4 | 0.08 | 103.65 | 0.001* |
| B* C | 0.76 | 4 | 0.19 | 234.12 | 0.001* |
| A*B*C | 0.63 | 8 | 0.08 | 98.13 | 0.001* |
| Error | 0.04 | 54 | 0.00 | | |
| Total | 51.52 | 80 | | | |

*A=Inclination, B=Height to Impact Point, C=Length to Impact Point, *=Significant @ 5%*

**Table 16. Comparing the mean values of output voltage using duncan multiple range test**

| Factor | Level | Turbine speed |
|---|---|---|
| Inclination | 15º above | 6.019a |
| | Tangential | 6.879b |
| | 15º below | 5.922c |
| Height to Impact | 200mm | 5.966a |
| | 250mm | 5.886b |
| | 300mm | 6.968c |
| Length to Impact | 50mm | 5.931a |
| | 100mm | 6.854b |
| | 150mm | 6.035a |

*Means with the same alphabet are not significantly different from each other*

**Table 17. Optimized values of process parameters and output**

| | Parameters | H | I | V | Optimized value | Nature of solution |
|---|---|---|---|---|---|---|
| Off-load | Turbine Speed | 250mm | Tangential | 150mm | 538.38 | Maximized |
| | Turbine Torque | 250mm | Tangential | 150mm | 46.15 | Maximized |
| On-load | Turbine Speed | 250mm | Tangential | 150mm | 392.02 | Maximized |
| | Turbine Torque | 250mm | Tangential | 150mm | 36.46 | Maximized |
| | Alternator Speed | 250mm | Tangential | 150mm | 1768.56 | Maximized |
| | Output Voltage | 250mm | Tangential | 150mm | 7.87 | Maximized |

*H=height to impact point, I=angle of inclination and V=length to impact point*

this was significantly higher than the output voltage observed at 250mm and 200mm respectively. Output voltage observed at the later levels (250mm and 200mm) are the same on the average. A higher output voltage of 6.85V was observed at 100mm Length to Impact Point. This value was significantly higher than output voltage observed at 150mm and 50mm respectively.

## 3.4 Optimization Analysis

### 3.4.1 Optimized value of process conditions and the output

Optimization is defined as the process of finding optimum (maximum or minimum) settings of parameters (process conditions) in the model in order to obtain a predefined output or response value.

The optimized value of process conditions namely, angle of inclination, height to impact point and length to impact point pre-set at their various levels and the optimum values of the process output or measured parameters are as presented in Table 17. The processes were optimized for both on load and off load.

### 3.4.2 Off-load condition

To optimize Turbine speed in off load condition, 250mm height to impact point, 150mm length to impact point and angle at tangential inclination will be required. This combination will yield an optimum Turbine speed of 538.38rpm. Similar combination will also yield an optimum Turbine Torque of 46.16kNm for the Pelton Wheel Turbine.

### 3.4.3 On-load condition

For the Pelton Wheel Turbine, Optimum Turbine speed of 392.02rpm was achieved at 250mm height to impact point, 150mm length to impact point and at tangential angle of inclination. Same operation combination will yield a Turbine Torque of 36.46kNm, and Alternator speed of 1768.56rpm and an output voltage of 7.87V.

## 3.5 Comparing Results with that of Other Researchers

As shown in Table 1, Panthee et al. [6] got a runner speed of 600rpm with a net head of 53.9m and flow rate of 0.05m$^3$/sec., Panagiotopoulos et al. [5] achieved a runner speed of 1000rpm with a net head of 100m, while Pdasaini et al. [7] got 600rpm runner speed with 80.85 m net head and 0.09218m$^3$/sec flow rate. In this research on the other hand, a runner speed of 538.38rpm was gotten with a head and flow rate of only 4 m and 0.017m$^3$/sec. The research is therefore novel as there has been no researcher as much as we know who has made use of the Pelton wheel at such low head. This is also an indication of the possibility of adapting the Pelton Wheel to low head if the operational conditions are adequately optimized.

## 4. CONCLUSION

The operational condition for the optimal performance of a Pelton wheel was investigated. It was found out that same conditions; 250 mm height to impact point, 150mm length to impact point and angle at tangential inclination gave the highest values in all measured parameters (Torque, Speed and Voltage) at both off-load and on-load condition. A direct proportionality was also observed between the alternator speed and the output voltage.

It is recommended that further research should be carried out on the optimization of nozzle sizes, number of Pelton wheel buckets, head, discharge, etc. on all the investigated parameters. Also, modelling of the system would make it easier to predict the effects of various conditions on the output.

## DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

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