Modern Applied Science; Vol. 9, No. 1; 2015
ISSN 1913-1844 E-ISSN 1913-1852
Published by Canadian Center of Science and Education

# Effect of the Bucket and Nozzle Dimension on the Performance of a Pelton Water Turbine

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Received: September 16, 2014 Accepted: October 9, 2014 Online Published: November 18, 2014

doi:10.5539/mas.v9n1p25 URL: http://dx.doi.org/10.5539/mas.v9n1p25

**Abstract**

Pelton turbine is an engine that facilitates continuous power as a wheel or a rotor continually turns due to the pressure of fast moving water through the bucket, where a bucket receives water from the surging nozzle. The objective of this research is to investigate the highest efficiency among different types of Pelton turbine through the modification of bucket volume, bucket angle attack, nozzle needle seat ring, and nozzle needle tip. The experiment was conducted at Energy Conversion Laboratory of Sebelas Maret University. The comparative study among the different parameters shows that the value of maximum efficiency was 21.65%, which was obtained at 90° needle seat ring and 45° needle tip, and +15% bucket size and 92° angle of attack. It was gained likely due to the lightness of the +15% bucket compared to the standard bucket and the collision produced by the jet water in the middle of the bucket, in which the water loading occupied the large area on the surface of the bucket and promoted the increasing speed. It is expected that the result on the appropriate size and angle attack of bucket at specific nozzle seat ring and nozzle tip of this experiment can be manufactured commercially in the future for achieving maximum Pelton turbine efficiency.

**Keywords:** pelton turbine, bucket, nozzle, efficiency

## 1. Introduction

Energy is one of the most fundamental elements of our universe. It is inevitable for survival and indispensable for development activities to promote education, health, transportation and infrastructure for attaining a reasonable standard of living and is also a critical factor for economic development and employment (Mohibullah & MohdIqbal, 2004). Hydropower is a renewable, non-polluting and environmentally benign source of energy. Hydropower is based on simple concepts. Moving water turns a turbine, the turbine spins a generator, and then electricity is produced. The use of water falling through a height has been utilized as a source of energy since a long time. It is perhaps the oldest renewable energy technique known to the mankind for mechanical energy conversion as well as electricity generation (Vineesh & Selvakumar, 2012). Hydropower on a small-scale is one of the most cost-effective energy technologies to be considered for rural electrification in less developed countries (Paish, 2002). Performance prediction of hydraulic machines, such as efficiency and dynamic behavior under different operating conditions, is of high interest to manufacturers (Kueny, 2006).

Micro-hydro-electric power is both an efficient and reliable form of clean source of renewable energy. It can be an excellent method of harnessing renewable energy from small rivers and streams. The micro-hydro project designed to be a run -of-river type, because it only requires very little or no reservoir in order to power the turbine. The water will run straight through the turbine and back into the river or stream to use it for the other purposes. This has a minimal environmental impact on the local ecosystem (Nasir, 2013). Micro-hydro power plants are an attractive option for providing electricity in off grid areas of the country (Loice Gudukeya, 2013). Pelton wheel turbine is one of the famous turbines which are mostly used for the hydro plants (Suraj Yadav, 2011). The design of Pelton turbines is mainly conducted from know-how and extensive experimental testing (Kueny, 2006). In impulse turbines water coming out of the nozzle at the end of the penstock is made to strike a series of buckets fitted on the periphery of the runner (Nasir, 2013). Impulse turbines generally operate best with medium or high head -above 10 m (Sangal, 2013).

## 2. Experimentation of Turbine

The main objectives of this experiment were to investigate the efficiency for many forms of Pelton for micro hydro through the modification of bucket volume, bucket angle attack, nozzle needle seat ring, and nozzle needle tip so as to get the best results of bucket volume, bucket angle attack, nozzle needle seat ring, and nozzle needle tip of Pelton turbine for micro hydro and to improve the water flow for Pelton turbine for micro hydro. The experiment was conducted at Energy Conversion Laboratory of Sebelas Maret University. The following are the experimental set up of research.

### *2.1 Description of Experimental Set Up*

The experimental setup consists of one pump and one turbine, which are connected in a closed loop with the help of PVC piping and water tank. The pump is used to create head. Suction pipe of pump draws water from water tank. Discharge pipe of pump is taken to the turbine side through closed piping and is connected to the turbine. The water flow to the turbine can be adjusted by means of a manually controlled throttle valve, fixed at the discharge of the pump. Turbine is installed up of the water tank to receive the water from the turbine. The tank is opened to atmosphere, and suction pipe of pump is connected to the water tank at the upper. Turbine is coupled to a generator through a rigid coupling. The generator is connected to load (incandescent lamp).

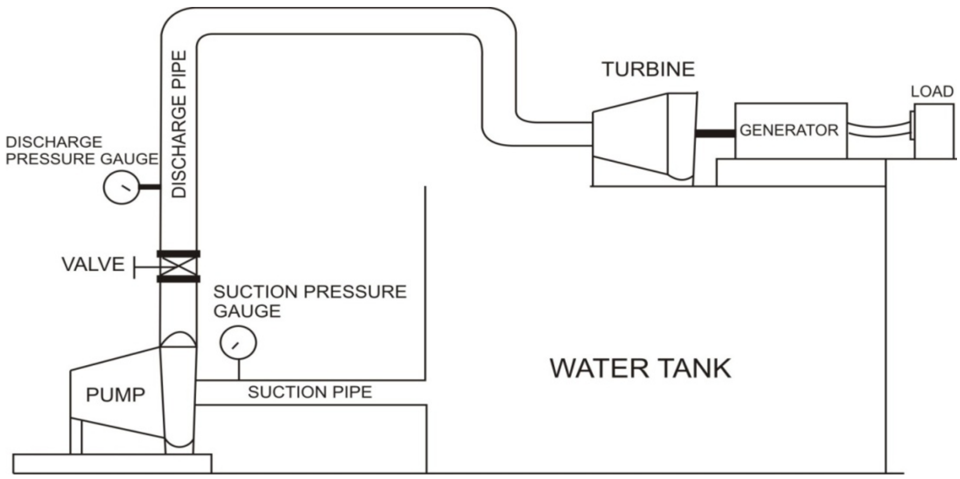


Figure 1. Experimental set up for Turbine Test

### *2.2 Head Measurement*

There are two pressure gauges used to calculate the net head. One of them is installed in a pipe before the pump (suction pressure) by cmHg and the other one is installed in a pipe after the pump (discharge pressure) by $kg/cm^2$. Then cmHg and $kg/cm^2$ are converted to meters of water by these equations:

*1 cmHg* = 0.136 meter of water

*1* $kg/cm^2$ = 10 meter of water

The head is calculated by this equation:

$$H = P_d - P_s \tag{1}$$

Where,

$P_s$ is suction pressure; and

$P_d$ is discharge pressure.

### *2.3 Water Flow Rate Measurement*

Flow rate is the amount of water flowing in the given time. The rate of water flow is calculated by using the equation below where the account time is needed to fill the 20-liter of tank.

$$Q = \frac{V}{t} \tag{2}$$

Where,

$V$ is volume ($m^3$) (1 L = 0.001 $m^3$); and

$t$ is time (second).

*2.4 Electric Power and Efficiency Measurement*

The generator is connected to DC lamp to measure voltage and current by voltmeter and ampere meter, respectively.

$$P_{output} = V \,.\, I \tag{3}$$

Where,

$V$ is voltage (volt); and

$I$ is current (ampere).

The efficiency is calculated by using the following formula:

$$\eta = \frac{Electrical\ power\ output}{Hydraulic\ power\ input\ to\ turbine} \tag{4}$$

Hydraulic power input to the turbine is calculated by the following formula:

$$P = \rho\, g\, HQ \tag{5}$$

Where,

$\rho$ is actual density of water (at actual temperature and pressure) in $kg/m^3$;

$g$ is actual acceleration due to gravity (function of latitude and altitude above mean sea level) in $m/s^2$;

$H$ is net head of water in m; and

$Q$ is discharge rate of water through the turbine in $m^3/s$.

**3. Method**

The first step of this research was collecting technical data and specification of the pump used for Pelton turbine and those for electricity generator specification. The data were used to design the Pelton turbine. Secondly, the the materials for Pelton turbine bucket and nozzle were obtained from some shops and manufacture companies for making the desired type of Pelton turbine bucket and nozzle at workshop based on the collected data. Then, two types of Pelton turbine buckets, two types of needle seat ring, and three types of needle tip were manufactured. Next, the volume of first specimen bucket was +15% of the standard volume with the angle of 92° whereas that of the second specimen bucket was -15% of the standard volume with the angle of 88°. Both had the same or less weights when compared to that of standard bucket. Lastly, the Pelton turbine buckets were tested. The test was executed in the conditions of 100%, 80%, 60% and 50% of the valve position to investigate the increasing efficiency. The tests also aimed at investigating the difference of the water flow of the new buckets from the standard one as to find out the electricity of generator affected by the flow of nozzle. Based on the results of tests, the best volume for Pelton turbine buckets was chosen.

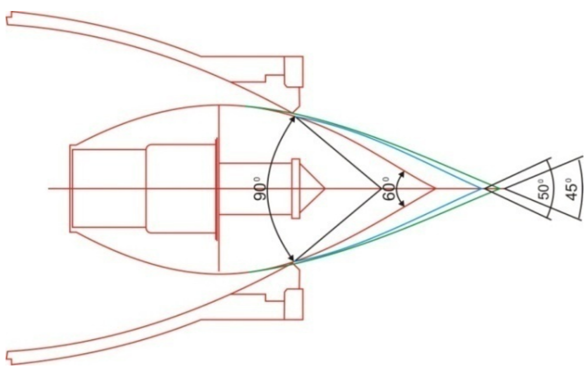


Figure 2. Red 90° Needle Seat Ring, Red 60° Needle Tip, Red 50° Needle Tip and Green 45° Needle Tip

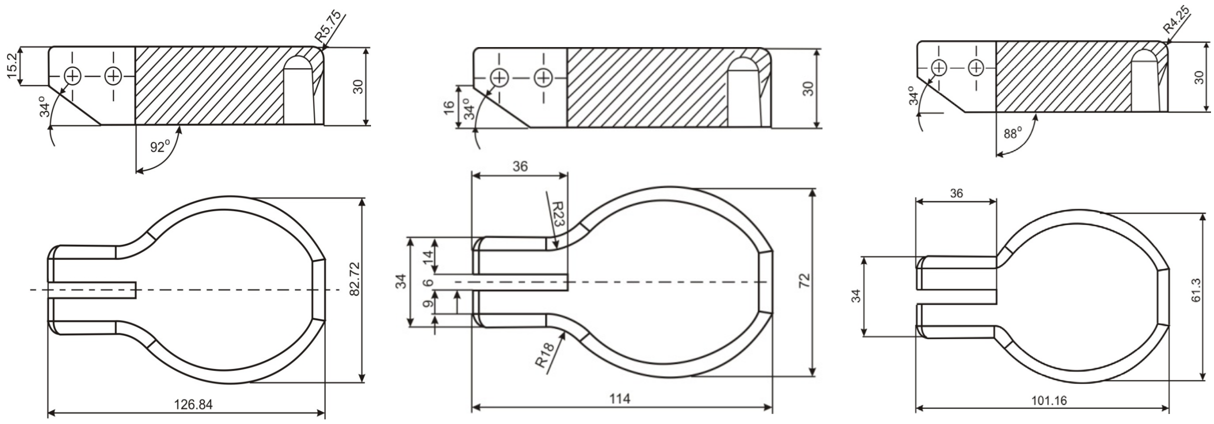


Figure 3. Standard bucket with 90° of angle attack, new bucket with +15% of dimensions, 92° of angle attack and -15% of dimensions, 88° of angle attack

The testing scheme for the modification of Pelton turbine buckets is presented in Figures 2 and 3. The water on the pump discharge was measured with flow meter (Q), and the pressure (P) was measured with pressure gauge. The water from nozzle was transformed to mechanical energy (spin). Then, the water hit the buckets. The efficiency (η) was counted from the mechanical power, and the electrical power from the generator was observed in volt meter and ampere meter.

### 3. Results

The results of tests and calculations are presented in several tables and curves. Table 1 shows the constant results of all buckets in nozzles with the 90° needle seat ring and the 60° needle tip.

Table 1. Constant results of all buckets in nozzle 90° needle seat ring, 60° needle tip

| | *Opening Valve* | *$P_{suction}$ (meter)* | *$P_{discharge}$ (meter)* | *Head (meter)* | *Flow Rate ($m^3/s$)* | *$P_{input}$ (watt)* |
|---|---|---|---|---|---|---|
| ***Nozzle needle seat ring 90°, needle tip 60°*** | *50%* | -0.408 | 11.5 | 11.908 | 0.000673 | 78.664 |
| | *60%* | -0.516 | 14.0 | 14.516 | 0.000755 | 107.479 |
| | *80%* | -0.544 | 15.0 | 15.544 | 0.000806 | 122.973 |
| | *100%* | -0.680 | 15.5 | 16.18 | 0.000847 | 134.513 |
| ***Nozzle needle seat ring 90°, needle tip 50°*** | *50%* | -0.884 | 5.7 | 6.584 | 0.000889 | 57.412 |
| | *60%* | -1.292 | 9.5 | 10.792 | 0.001105 | 116.982 |
| | *80%* | -2.176 | 10.5 | 12.676 | 0.001198 | 148.924 |
| | *100%* | -2.380 | 12.0 | 14.38 | 0.001307 | 184.402 |
| ***Nozzle needle seat ring 90°, needle tip 45°*** | *50%* | -0.952 | 2.0 | 2.952 | 0.000905 | 26.207 |
| | *60%* | -1.768 | 6.5 | 8.268 | 0.001223 | 99.216 |
| | *80%* | -2.584 | 10.0 | 12.584 | 0.001493 | 184.252 |
| | *100%* | -2.951 | 11.0 | 13.951 | 0.001646 | 225.286 |

In table1, the individual constant results of the three kinds of turbine bucket. The results are fixed at the same valve position. The first column after valve position is the suction pressure, followed by suction pressure converter to the meter, and then the discharge pressure, followed by discharge pressure converter to the meter and the column head, which is the sum decrement the suction pressure of the discharge pressure. Thus, the more opening valve, the higher the head it achieves. The next column is the flow rate which is the sum divided by the time to fill 20 liters of tank after converting it to cubic meter and volume. Therefore, the lesser the time, the higher the water flow rate it achieves for separate nozzles. Finally, the last column it the power input (mechanical power for turbine).

The results obtained from the experimental set up and the different measureable factors at different bucket types with 90° needle seat ring and the 60° needle tip of nozzle are presented in Table 2.

Table 2. Results of Different Parameters at different bucket types and 90° needle seat ring and 60° needle tip of nozzle

| *Nozzle 90°needle seat ring and 60° needle tip* | | | | | | |
|---|---|---|---|---|---|---|
| *Bucket type* | *Opening Valve* | *rpm* | *Voltage (volt)* | *Current (ampere)* | *$P_{output}$ (watt)* | *Efficiency (%)* |
| ***Standard Bucket Size and 90°Angle Attack*** | 50% | 96 | 2.0 | 1.20 | 2.40 | 3.05 |
| | 60% | 110 | 2.5 | 1.35 | 3.37 | 3.14 |
| | 80% | 130 | 3.1 | 1.52 | 4.71 | 3.83 |
| | 100% | 170 | 3.5 | 1.62 | 5.67 | 4.21 |
| ***+15% Bucket Size and 92° Angle Attack*** | 50% | 105 | 2.1 | 1.20 | 2.58 | 3.27 |
| | 60% | 112 | 2.6 | 1.40 | 3.64 | 3.38 |
| | 80% | 140 | 3.4 | 1.50 | 5.10 | 4.14 |
| | 100% | 185 | 3.8 | 1.60 | 6.08 | 4.51 |
| ***-15% Bucket Size and 88°Angle Attack*** | 50% | 78 | 1.4 | 0.95 | 1.33 | 1.69 |
| | 60% | 90 | 1.7 | 1.20 | 2.04 | 1.89 |
| | 80% | 100 | 2.1 | 1.35 | 2.83 | 2.30 |
| | 100% | 110 | 2.3 | 1.42 | 3.26 | 2.42 |

The graph in Figure 4 depicts the disparity in efficiency for three kinds of bucket size and angle attack at bucket types with the 90° needle seat ring and the 60° needle tip of nozzle. The X-axis and Y-axis represent the valve opening and efficiency of micro hydraulic Pelton, and the three different colors indicate the three different bucket types.

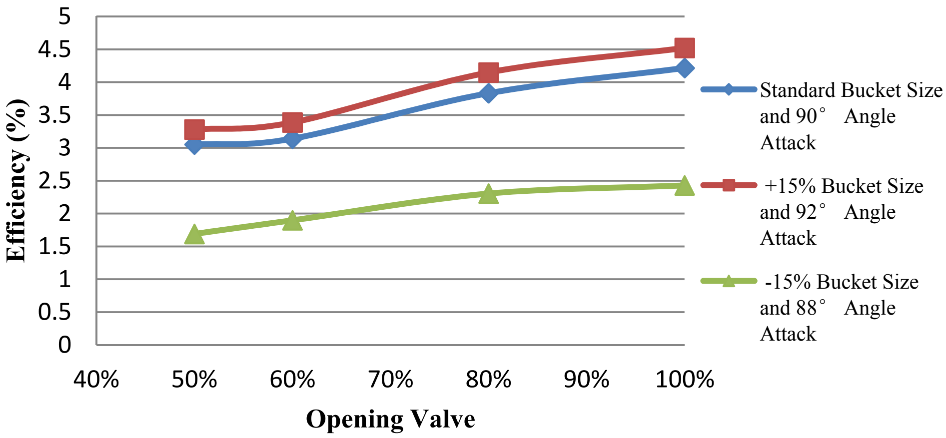


Figure 4. A view of the relation between the valve opening and efficiency at different bucket size and angle attack at nozzle 90° needle seat ring and 60° needle tip

The figure indicates that the overall view of this line graph shows an ostensive trend whereas the +15% bucket and standard bucket show the similar pattern of intercourse and if compared to these two bucket sizes, the -15%bucket reveals a little different movement in term of showing efficiency rate at different valve opening.

At first the efficiency rate stands at 3.05% and 3.28% approximately for standard and +15% bucket size at 50% valve opening. Afterwards, it rises steadily by .09% and .11% for both of them from 50% to 60% valve opening. Since then both the standard and +15% bucket size show a gradual rise of efficiency until ending at 100% valve opening, from 3.14% to 4.22% and 3.39 to 4.52%, respectively. On the other hand, since the beginning to ending -15% bucket always follows a gentle increase of efficiency rate, from 1.69% to 2.43%.

The results obtained from experimental set up and the different measureable factors at three different bucket types with the 90° needle seat ring and the 50° needle tip of nozzle are shown in Table 3.

Table 3. Results of Different Parameters at different bucket types and 90° needle seat ring and 50° needle tip of nozzle

| *Nozzle 90° needle seat ring and 50°needle tip* | | | | | | |
|---|---|---|---|---|---|---|
| *Bucket type* | *Opening Valve* | *rpm* | *Voltage (volt)* | *Current (ampere)* | *$P_{output}$ (watt)* | *Efficiency (%)* |
| ***Standard*** | 50% | 110 | 2.6 | 1.20 | 3.12 | 5.43 |
| ***Bucket Size*** | 60% | 180 | 5.5 | 1.95 | 10.72 | 9.16 |
| ***and 90° Angle*** | 80% | 236 | 8.0 | 2.50 | 20.00 | 13.42 |
| ***Attack*** | 100% | 305 | 11.6 | 3.20 | 37.12 | 20.12 |
| ***+15% Bucket*** | 50% | 115 | 2.8 | 1.20 | 3.36 | 5.85 |
| ***Size and 92°*** | 60% | 190 | 5.5 | 2.10 | 11.59 | 9.90 |
| ***Angle Attack*** | 80% | 345 | 8.1 | 2.60 | 21.19 | 14.22 |
| | 100% | 315 | 11.7 | 3.28 | 38.54 | 20.89 |
| ***-15% Bucket*** | 50% | 85 | 2.2 | 1.00 | 2.25 | 3.91 |
| ***Size and*** | 60% | 130 | 3.1 | 1.58 | 4.89 | 4.18 |
| ***88°Angle*** | 80% | 185 | 5.5 | 2.00 | 11.00 | 7.38 |
| ***Attack*** | 100% | 210 | 6.2 | 2.35 | 14.61 | 7.92 |

The graph in Figure 5 shows the difference in efficiency for three kinds of bucket size and angle attack at bucket types with the 90° needle seat ring and the 50° needle tip of nozzle. The X-axis and Y-axis represent the valve opening and efficiency of micro hydraulic Pelton, and the three different colors indicate the three different bucket types.

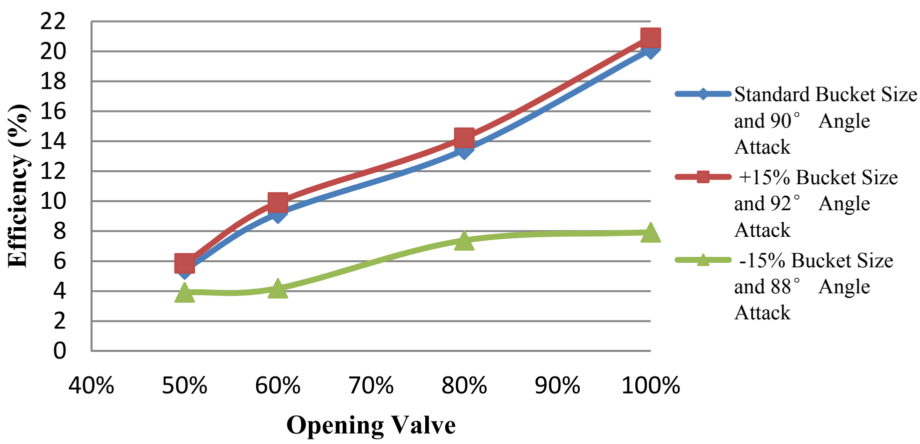


Figure 5. A view of the relation between the valve opening and efficiency at different bucket size and angle attack at nozzle 90° needle seat ring and 50° needle tip

From the above figure, it is obvious that the overall view of this line graph shows upward trend whereas the +15% bucket and standard bucket show the similar pattern of movement, and if compared to these two bucket sizes, the -15% bucket demonstrates a slight different intercourse in term of showing efficiency rate at different valve opening. At first the efficiency rate stands at 5.43 % and 5.85 % roughly for standard and +15% bucket size at 50% valve opening. Afterwards, it increases significantly by 14.7 % and 14.98 % roughly for both of them from 50% to 100 % valve opening. At the beginning, -15% bucket starts moving in a very steady speed from 50% to 60% valve opening, from 3.92% to 4.19% roundly of efficiency. Then, the efficiency rate rises gently by 3.20% approximately from 60% to 80% valve opening. In the end, the -15% bucket shows a very slight increase of efficiency rate, from 7.39% to 7.93% roughly.

The results obtained from experimental set up and the different measureable factors at three different bucket types with the 90° needle seat ring and the 45° needle tip of nozzle are presented in Table 4.

Table 4. Results of Different Parameters at different bucket types and 90° needle seat ring and 45° needle tip of nozzle

| *Nozzle 90° needle seat ring and 45° needle tip* | | | | | | |
|---|---|---|---|---|---|---|
| *Bucket type* | *Opening Valve* | *rpm* | *Voltage (volt)* | *Current (ampere)* | *$P_{output}$ (watt)* | *Efficiency (%)* |
| ***Standard*** | 50% | 100 | 2.0 | 1.18 | 2.36 | 9.00 |
| ***Bucket Size and*** | 60% | 210 | 6.7 | 2.27 | 15.20 | 15.32 |
| ***90° Angle*** | 80% | 310 | 11.5 | 3.10 | 35.65 | 19.14 |
| ***Attack*** | 100% | 335 | 13.3 | 3.35 | 44.55 | 19.87 |
| ***+15% Bucket*** | 50% | 130 | 2.5 | 1.24 | 3.10 | 11.82 |
| ***Size and*** | 60% | 215 | 7.0 | 2.30 | 16.10 | 16.22 |
| ***92°Angle*** | 80% | 315 | 12.0 | 3.20 | 38.40 | 20.61 |
| ***Attack*** | 100% | 340 | 14.4 | 3.37 | 48.52 | 21.64 |
| ***-15% Bucket*** | 50% | 92 | 1.8 | 1.02 | 1.88 | 7.20 |
| ***Size and*** | 60% | 140 | 3.7 | 2.10 | 7.77 | 7.83 |
| ***88°Angle*** | 80% | 210 | 7.0 | 2.50 | 17.50 | 9.39 |
| ***Attack*** | 100% | 225 | 7.9 | 2.70 | 21.33 | 9.51 |

The graph in Figure 6 illustrates the distinction in efficiency of three kinds of bucket size and angle attack, 90° needle seat ring and 45° needle tip of nozzle. The X-axis and Y-axis represent the valve opening and efficiency of micro hydraulic Pelton, and the three different colors indicate the three different bucket types.

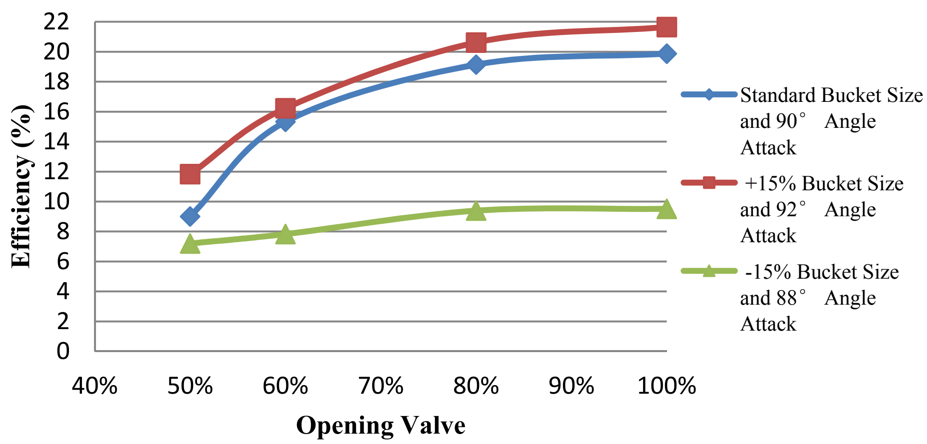


Figure 6. A view of the relation between the valve opening and efficiency at different bucket size and angle attack at nozzle 90° needle seat ring and 45° needle tip

From the above figure, it is clear that the overall view of this line graph shows an ascending trend whereas the +15% bucket and standard bucket show the similar pattern of pathway, and if compared to these two bucket sizes, the -15% bucket reveals a slight different movement in term of showing efficiency rate at different valve opening.

Initially the efficiency rate stands at 9% and 11.83% roughly at 50% valve opening, respectively for both standard as well as +15% bucket. Afterwards, from 50% to 80% the rate of efficiency rises substantially by 10.14% and 8.79%, respectively for both buckets. In the end, both bucket, standard and +15% bucket, shows a steady rise of efficiency, from 19.14 to 19.87 and from 20.62 to 20.65%, respectively. On the other hand, since the beginning to ending the -15% bucket shows a slow rise of efficiency, from 7.20% to 9.51%. The minimum turbine efficiency is found in -15% bucket size with the 88° angle attack due of the weakness positioning of the nozzle when the collision is produced by water jet to the bucket as the jet water pushes the bucket in the end of bucket, which leads to the low efficiency of the turbine. The initial test unit requires readjustment due to poor positioning and misalignment of the nozzle with respect to the turbine runner (Bryan Patrick Ho-Yan, 2012).

From the above discussion it is obvious that there is a linear relationship between the valve opening and the efficiency value. The maximum turbine efficiency is seen at the full opening of the valve for all kinds of bucket. There are differences in the turbine efficiency between the buckets. The maximum turbine efficiency is 1.65 % , which is found in +15% bucket size with the 92° angle attack at 90° needle seat ring and 45° needle tip due to the lightness of the +15% bucket compared to the standard bucket, and the collision is produced by the jet water in the middle of the bucket, which occupies the largest area on the surface of the bucket and helps to increase the speed, and thus produces the higher efficiency as shown in Figure 5. Since the distance between nozzle needle seat ring and needle tip is constant, it gives the 90° needle seat ring and the 45° needle tip an appropriate distance between them, and this helps to increase the jet water and thus the efficiency becomes higher. In contrast to the other angles, when the distance between needle seat ring and needle tip is narrow, the velocity of water and efficiency detract.

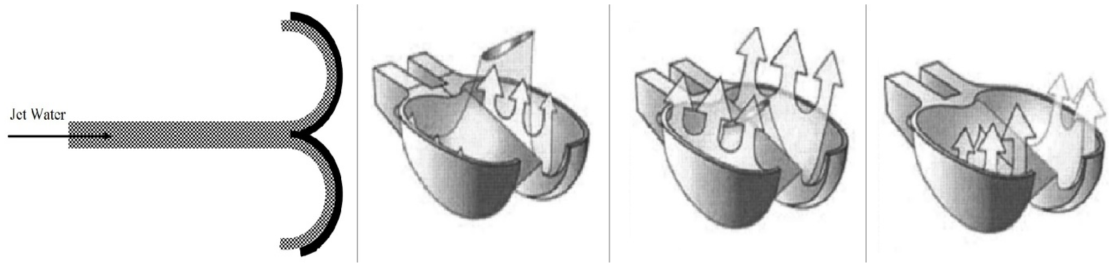


Figure 7. Jet Water

## 4. Conclusion

The experiment was carried out with great care. The results of research show that there is a proportional relationship between the efficiency rate and the size of bucket and angle attack. The value of the highest efficiency was 21.65% which was found in +15% bucket size and 92° angle attack at 90° needle seat ring and 45° needle tip. It was achieved probably due to the lightness of the +15% bucket compared to the standard bucket and the collision produced by the jet water in the middle of the bucket, ensuring that the water loading occupied the large area on the surface of the bucket, which increased the speed. It is expected that that the result on the size and angle attack of bucket at specific nozzle seat ring and seat tip of this experiment can be manufactured commercially in the future for achieving maximum Pelton turbine efficiency.

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