

PAPER • OPEN ACCESS

## Optimization Of Angle Deflection on Pelton Turbine Bucket Using CFD

To cite this article: Mochamad Ghani Hanif Suryaningrat and Rosyida Permatasari 2025 *J. Phys.: Conf. Ser.* **2972** 012018

View the [article online](#) for updates and enhancements.

### You may also like

- [A review of the experimental techniques research progress of the Pelton turbine](#)  
Gui Zhonghua, Xiao Yexiang, Li Dongkuo et al.
- [Numerical prediction of hydraulic performance in model and homologous prototype Pelton turbine](#)  
C J Zeng, Y X Xiao, J Zhang et al.
- [Investigation on large fluctuation transient process of high head Pelton turbine](#)  
J Gao, L Han, H J Wang et al.

# Optimization Of Angle Deflection on Pelton Turbine Bucket Using CFD

Mochamad Ghani Hanif Suryaningrat<sup>1</sup>, Rosyida Permatasari<sup>1\*</sup>

<sup>1</sup> Mechanical Engineering Department, Universitas Trisakti, Jakarta, Indonesia

\*[rosyida@trisakti.ac.id](mailto:rosyida@trisakti.ac.id)

\*0000-0001-6621-0359

**Abstract.** The Pelton turbine is a type of water turbine that is often used in hydroelectric power plants. This Pelton turbine is generally used for locations with a head height of more than 30 meters. The water in the Pelton turbine moves fast, and it extracts energy from the water by slowing down the water, making it an impulse turbine. This study aimed to determine the optimal efficiency of the Pelton turbine by analyzing the blade design using variations in the deflection angle. The fluid flow velocity from the bucket with variable deflection angles of 15°, 17°, and 19° was analyzed using the Computational Fluid Dynamics (CFD) method with SolidWorks simulation software. The simulation data were then analyzed and described using the velocity triangle method. From the simulation, the largest value of turbine power is 329,54kW, and efficiency is 95.98% at an angle of 15° with a discharge of 0.35 m<sup>3</sup>/s.

## 1. Introduction

The ongoing use of conventional energy resources can lead to many problems such as carbon pollution, the greenhouse effect, and others. Therefore, the world has started to reconsider and encourage research towards alternative energy, namely using new and renewable energy. One of the alternative energy options that has great potential is water energy.

Indonesia is a country located on the equator; therefore, the existence of Indonesian territory has a wide variety of alternative energy sources, likely water energy can be used to meet the increasing energy needs. According to data from the Ministry of Energy and Mineral Resources (Energy and mineral resources), Indonesia's hydropower potential can reach 75,000 MW and only about 10% has been empowered. One of the uses of water energy is the Micro Hydro Power Plant (PLTMH) which is one of the solutions for current energy [1].

The Pelton turbine's working principle uses water hydraulic energy to generate shaft power. In the Pelton turbine, the potential energy of water is converted into kinetic energy through a nozzle that is emitted into the bucket to be converted into mechanical energy which is used to rotate the generator shaft which plays the main role of the source to generate electric current [1], [2].

This Pelton turbine is an impulse-type turbine commonly used for high heads. The efficiency of the Pelton turbine is not so great when it is compared with reaction or axial turbines, because most of its energy is wasted from the waste of water separation that is not used and the result is just wasted [1]. This study aims to help see the optimal efficiency of the Pelton turbine by analyzing the blade design using variations in the deflection angle [3].



This research was conducted using the Computational Fluid Dynamics (CFD) method, a system analysis method involving fluid flow, heat transfer, and other related phenomena using computer simulation. Using CFDs makes it easy to configure bucket dimensions and fluid properties. CFD code is composed of a numerical algorithm that can solve fluid flow problems [4].

## 2. Literature Review

In research conducted by Bilal (2013), the article entitled Design of high-efficiency Pelton turbine for a micro hydropower plant, some parameters included turbine power, turbine torque, runner diameter, runner length, runner speed, bucket dimensions, number of buckets, nozzle dimension, and turbine specific speed were calculated at maximum efficiency [5].

In research conducted by Suraj Yadav (2011), the article entitled Some Aspects of Performance Improvement of Pelton Wheel Turbine with Reengineered Blade and Auxiliary Attachments, the simulation was carried out at a deflection angle of  $15^\circ$ , with a runner diameter of 2.06 m, operating speed of 250 rpm, head 670.6 m, nozzle speed 114.6 m/s, blade speed = 53.86 m/s, This wheel probably develops about 60,000 hp at a flow of about  $7 \text{ m}^3/\text{s}$  [6].

In research conducted by Kiki Ananda Siahaan (2020), the article entitled The Effect of the Number of Nozzles on the Performance of the Pelton Turbine Prototype. Testing the effect of the number of nozzles on turbine performance with a pump capacity of 200 liters/min, pump power of 0.75 Kw, and pump head of 12 m, the best installation is to use one number of nozzles [7].

The turbine bucket geometry design is made with the dimensions of a top length of 0.15 m, a top width of 0.1 m, and a top radius of 0.03 m, while the bottom length is 0.7 m, the bottom width is 0.7 m, and the bottom radius is 0.02 m.

## 3. Simulation

### 3.1 Work Principle

Figure 1 describes Pelton Turbine works as follows [1]:

- 1) Water is removed from the reservoir through a long channel called a penstock.
- 2) The nozzle arrangement at the tip of the penstock helps the water to accelerate and flow out as a high-velocity jet at high velocity and discharge at atmospheric pressure.
- 3) The jet will hit the splitter bucket which will distribute the jet into two parts of the bucket and the wheel will start to spin.
- 4) The kinetic energy of the jet is reduced when it hits the bucket because the shape of the bucket jet is directed to change direction, take a reverse direction, and fall into the tail race.
- 5) Generally, the angle of the inlet of the beam is between  $1^\circ$  to  $3^\circ$ , after hitting the bucket the angle of the deflected beam is between  $165^\circ$  to  $170^\circ$ .

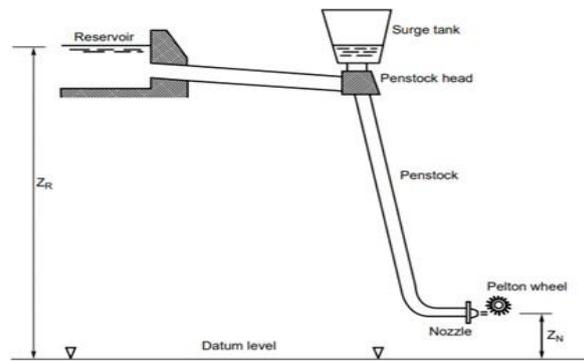


Figure 1. Pelton Turbine Work Principle [1]

### 3.2 Velocity Triangle

Figure 2 gives a jet of water from the nozzle that hits the splitter symmetrically and is evenly distributed into the two halves of the hemispherical blade. The beam entry angle ranges from 1° to 3° but is considered zero in all calculations. Then the relative velocity of the jet leaving the bucket will be opposite to the relative velocity of the incoming jet. This is not achievable in practice because the jet leaving the bucket will then hit the next rear end causing a disturbance so the overall turbine efficiency will drop. Therefore, in practice, the beam angle deflection in the bucket is limited to about 165° to keep the beam clean from the next bucket [3].

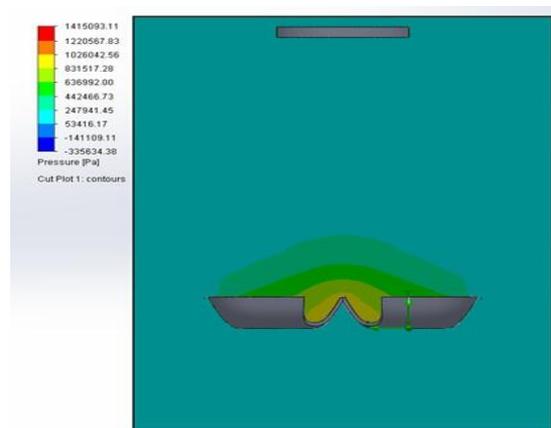


Figure 2. Velocity Triangle [8]

The ideal speed has the following equation [8]:

$$V = \sqrt{2 \cdot g \cdot H} \tag{1}$$

### 3.3 Turbine Efficiency

Efficiency is the value of the level of use or the ratio of resources in a process, the efficiency of a turbine can be calculated using the formula [8]:

$$\eta_t = \frac{P_t}{P_a} \times 100\% \tag{2}$$

Water power can be calculated by the formula [8]:

$$P_a = \rho \cdot g \cdot Q \cdot H \quad (3)$$

Turbine power can be calculated by the formula [8]:

$$P_t = \rho \cdot Q \cdot (V_1 - u) \cdot (1 + K \cos \theta) \cdot u \quad (4)$$

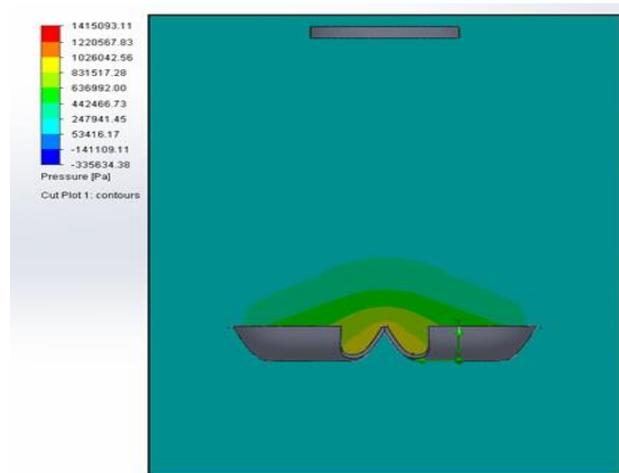
Theoretically, maximum efficiency occurs below  $0.5 V_1$ , whereas there is a condition the maximum efficiency value can be determined by the following equation [8]:

$$\eta_{h \max} = \frac{(1 + \cos \theta)}{2} \quad (5)$$

## 4. Results and Discussion

### 4.1 Pressure Contour

Figure 3 shows the distribution of the pressure contour around the bucket. The color differences indicate the strength of the pressure, from yellow (high pressure) to green (low pressure). The research results on the distribution of the pressure contour area show that the smaller the deflection angle, the greater the pressure.



**Figure 3.** Distribution of Pressure Contour around the Bucket

### 4.2 Fluid Flow Outlet Velocity

From the following table data (Table 1 – Table 3), the average outlet speed from both directions is determined and the resultant relative outlet velocity ( $v_{rrr}$ ) is searched (Table 4).

**Table 1.** Goals Results in Angle 15°

Goals	Unit	Value
PG Velocity (Y) 1	[m/s]	18.54
PG Velocity (Z) 1	[m/s]	13.62
PG Velocity (Y) 2	[m/s]	18.39
PG Velocity (Z) 2	[m/s]	-13.46

**Table 2.** Goals Results in Angle 17°

Goals	Unit	Value
PG Velocity (Y) 1	[m/s]	19.36
PG Velocity (Z) 1	[m/s]	12.88
PG Velocity (Y) 2	[m/s]	19.19
PG Velocity (Z) 2	[m/s]	-12.81

**Table 3.** Goals Results in Angle 19°

Goals	Unit	Value
PG Velocity (Y) 1	[m/s]	23.36
PG Velocity (Z) 1	[m/s]	-16.56
PG Velocity (Y) 2	[m/s]	23.30
PG Velocity (Z) 2	[m/s]	16.70

**Table 4.** Relative Outlet Velocity of Fluid Flow

Angle	Unit	Vy	Vz	Vr2
15°	[m/s]	18.47	13.54	25.57
17°	[m/s]	19.27	12.84	26.09
19°	[m/s]	23.33	16.63	32.76

Figure 4 gives a fluid flow velocity trajectory with a decrease in velocity due to flow collisions on the bucket, the nozzle diameter carried out in the simulation is 0.1 m for an angle of 15°.

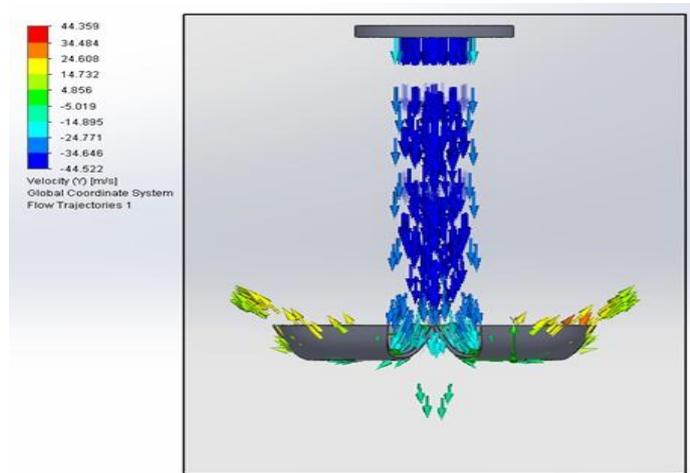


Figure 4. Trajectory Angular velocity for angle 15°

4.3 Calculation Results

Finding bucket speed where  $v_{r1} = v_{r2}$ :

$$v = u + v_{r1} \tag{6}$$

$$u = v - v_{r2} \tag{7}$$

Finding turbine power:

$$P_t = \rho \cdot Q(v - u)(1 + \cos\theta) \cdot u \tag{8}$$

For example, at an angle of 15°:

$$P_t = 1000 \cdot 0.35 \cdot (44.3 - 18.73) \cdot (1 + \cos(15)) \cdot 18.73$$

$$= 329536.6161 \approx 329.537 \text{ kW}$$

Finding Efficiency:

$$\eta_t = \frac{P_t}{P_a} \times 100\% \tag{9}$$

$$= \frac{\rho \cdot Q(v - u)(1 + \cos\theta) \cdot u}{\rho \cdot g \cdot Q \cdot H} \times 100\%$$

$$= \frac{329,537}{1000 \cdot 9.81 \cdot 0.35 \cdot 100} \times 100\% = 95.98\%$$

95.98%

The total results of the value of bucket speed, turbine power, and efficiency from angles of 15°, 17°, and 19° can be seen in Table 5.

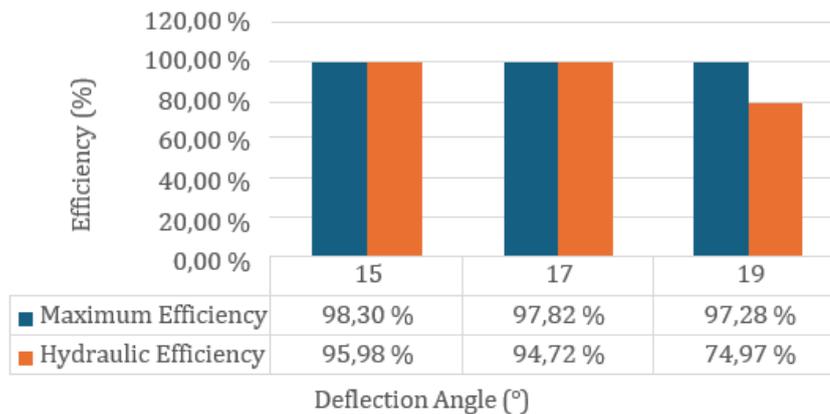
**Table 5.** Relative output velocity of fluid flow

(°)	u	P <sub>t</sub>	η
15	18.73 m/s	329.54 kW	95.98 %
17	18.21 m/s	325.30 kW	94.72 %
19	11.54 m/s	257.43 kW	74.97 %

**4.4 Analysis**

Figure 5 shows that the highest theoretical maximum efficiency value is found at the corner with an efficiency value of 98.3%, followed by an angle with an efficiency value of 97.82%, and an angle with an efficiency value of 97.28 %.

By comparing the simulated hydraulic efficiency with the theoretical maximum efficiency, it can be stated that there is a correlation between the increase in efficiency values with a smaller deflection angle, but in the simulation hydraulic efficiency, there is a significant decrease in the value at the possible angle due to the geometric design of the model that does not precise the original design.



**Figure 5.** Effect of bucket deflection angle on efficiency

**5. Conclusion**

The results of the simulation of fluid flow in the Pelton turbine bucket with variations in deflection angles of 15°, 17°, and 19°, show that the 15° angle has the largest turbine power and efficiency values, namely 329.54 kW and 95.98%. These values are not so far different from the angle of 17° with the value of turbine power and efficiency of 325.30 kW and 94.72%, respectively.

Besides that, there is a correlation between analytical and simulation methods with real phenomena that smaller deflection angles can increase efficiency and that the optimal range is between 15° - 17° and no more.

For further research, it should be able to perform a simulation with more complex bucket geometry following the shape of a half ball or spoon so that the data results from the simulation can be analyzed more accurately.

### Acknowledgment

We thank the Department of Mechanical Engineering, Faculty of Industrial Technology, Universitas Trisakti who greatly assisted the research, until the completion of this research.

### References

- [1] Z. Zhang 2016 *Pelton Turbines*. Zurich: Springer International Publishing Switzerland
- [2] E. Quaranta and C. Trivedi 2021 The state-of-art design and research for Pelton turbine casing, weight estimation, counterpressure operation and scientific challenges *Heliyon* **7** 12 e08527
- [3] A. Rossetti, G. Pavesi, G. Cavazzini, A. Santolin, and G. Ardizzon 2014 Influence of the bucket geometry on the Pelton performance *Proc. Inst. Mech. Eng. Part A J. Power Energy* **228** 1 33–45
- [4] G. Giraldo 2024 CFD Modeling, Analysis, and Online Simulation For Beginners *SIMSCALE Blog*
- [5] B. A. Nasir 2013 Design of High-Efficiency Pelton Turbine for MicroHydro Power Plant *Int. J. Electr. Eng. Technol.* **4** 1 171–184
- [6] S. Yadav 2011 Some Aspects of Performance Improvement of Pelton Wheel Turbine with Reengineered Blade and Auxiliary Attachments *Int. J. Sci. Eng.* **2** 9 2–5
- [7] I. M. Ardika Tommy Saputra, L. Jasa, and I. W. Arta Wijaya 2020 Pengaruh Tekanan Air Dan Sudut Nozzle Terhadap Karakteristik Output Pada Prototype Pltmh Dengan Turbin Pelton *J. SPEKTRUM* **7** 4 17 (in Bahasa)
- [8] S. L. Dixon and C. A. Hall 2010 *Fluid Mechanics and Thermodynamics of Turbomachinery* 7th ed. Elsevier Inc.