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Influence of Splitter Angle Variations on the Efficiency and Power of Pelton Turbine

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Abstract

The Pelton turbine is a type of impulse turbine engineered to exploit the potential energy of high-pressure, low-flow water. A pivotal component of the Pelton turbine bucket is the splitter, which serves as a separator at the core of the bucket, bifurcating the water-jet flow into two symmetrical segments. The splitter modulates the distribution and trajectory of the water flow after it impacts the bucket surface. This study examined the effects of splitter-angle variations on the efficiency and power of a Pelton turbine. The turbine was designed with 20 ABS blades fabricated using 3D printing technology and assessed under splitter-angle configurations of 15°, 25°, 50°, 75°, 100°, and 125°, as well as in the absence of a splitter. Four discharges (0.000692; 0.000663; 0.000642 and 0.000623 m^3/s) and various loads, starting from 0.2 to 3.0 kg, with a range of 0.2, were tested. The findings indicate that the splitter angle profoundly affects turbine efficiency, with the 50° angle producing the highest efficiency and power of 89% and 24 W, respectively, at a load of 2.0 kg, a turbine rotation of 285 rpm, and a torque of 0.8044 Nm, with a discharge of 0.000692 m^3/s. The experimental and simulation results emphasize the importance of optimizing the splitter geometry to improve energy conversion efficiency and overall turbine performance.

1 Introduction

The total potential of hydropower in Indonesia is estimated at approximately 95 GW, but only approximately 6.7–7 GW has been realized, representing only 7–9% of the total potential. The Indonesian Ministry of Energy and Mineral Resources cites a potential of 89.37 GW, spread across 293 locations, categorized as dams (approximately 14.7 GW) and lakes (approximately 74.7 GW) [1]. Indonesia's hydropower potential is abundant and distributed across various power plant capacities, ranging from microhydro to large-scale (conventional) plants. At the microhydro scale, with a capacity range of 5–100 kW, the available potential reaches approximately 460 MW [2]. However, the utilization rate remains relatively low at approximately 4.5%. Nevertheless, micro-hydro power plants have the advantage of supplying electricity to rural or remote areas that are difficult to reach via the main power grid, thereby playing a strategic role in supporting renewable-energy-based electrification [3]. At the mini-hydro scale, with capacities ranging from 100 kW to 1 MW [4], the available potential constitutes approximately 770

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MW of the total in the mini/macro-hydro category. These power plants are generally more flexible than large hydroelectric power plants because they can utilize rivers with relatively small flows without the need to build large dams [5]. Pelton turbines are widely used in microhydro and mini-hydro power plants because their operation is easy to implement in rural areas with small river flows, as they only require a high head [6]. These turbines fall under the impulse category [7] because they use nozzle pressure to increase the water pressure on the Pelton turbine blades [8]. The main component of the Pelton turbine is the splitter [9]. The splitter optimally distributes the water flow to the turbine blades, thereby maximizing the turbine's power and efficiency [10]. The splitter's function is influenced by its geometry; the more aerodynamic the shape, the more optimal the water flow distribution to the blades [11]. The splitter design in a Pelton turbine is a key focus because it directly influences the distribution of water flow across the blades and determines how it interacts with the blade surface. Several studies have shown that variations in the splitter's shape can affect turbine performance, including mechanical efficiency. Therefore, it is important to understand how variations in the double splitter on the blades affect the turbine's overall performance. Chukwuneke found that changes in the bucket-splitter angle affect the output power of a Pelton turbine [12]. Jorge analyzed the influence of the splitter angle on the force generated by a bucket using Fluent [13]. Rupa developed a methodology for modeling flow deflection on Pelton turbine blades, which was then applied at the microscale. Despite these deviations, the results still showed a trend consistent with theoretical and experimental data reported in the literature [14].

2 Methodology

This study employed an experimental approach. The Pelton turbine incorporated 20 blades fabricated from ABS via 3D printing. The splitter configuration was evaluated across six angle variations (15°, 25°, 50°, 75°, 100°, and 125°) and compared with no splitter, as shown in Figures 1-10. The turbine dimensions were as follows: runner diameter, 300 mm; shaft diameter, 25 mm; shaft length, 765 mm; blade width, 80 mm; and blade length, 100 mm. The nozzle diameter was 10 mm, and the nozzle-to-runner distance was 10 cm. Moreover, the nozzle is aligned with the shaft. The principal components of the investigation were the pump, reservoir, turbine, valve, and pipes. The flow rate variations are 0.000692 m^3/s, 0.000663 m^3/s; 0.000642 m^3/s; 0.000623 m^3/s. The turbine load variations are 0.2; 0.4; 0.6; 0.8; 1; 1.2; 1.4; 1.6; 1.8; 2.0; 2.2; 2.4; 2.6; 2.8; 3 kg. The radius of the load pulley was 0.41 mm. The turbine rotation was measured with a digital tachometer, and the flow rate was determined by filling a bucket to capacity and measuring the time. Subsequently, torque is calculated by multiplying the load mass, the gravitational acceleration, and the pulley's radius.

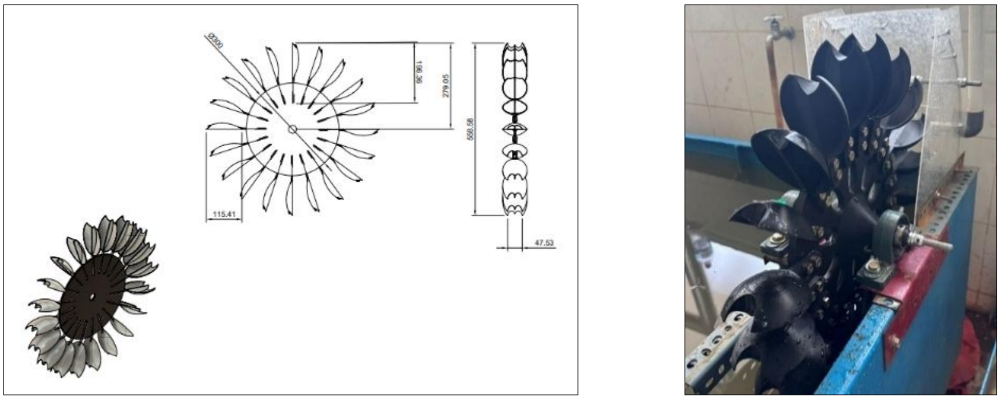

Figure 1. Design of pelton turbine

Figure 2. No splitter

Figure 3. Angle splitter 15°

Figure 4. Angle splitter 25°

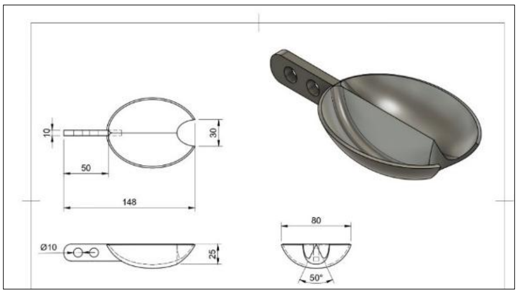

Figure 5. Angle splitter 50°

Figure 6. Angle splitter 75°

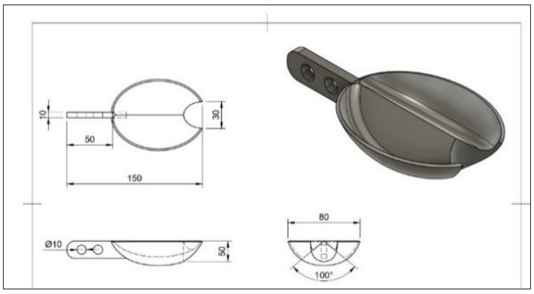

Figure 7. Angle splitter 100°

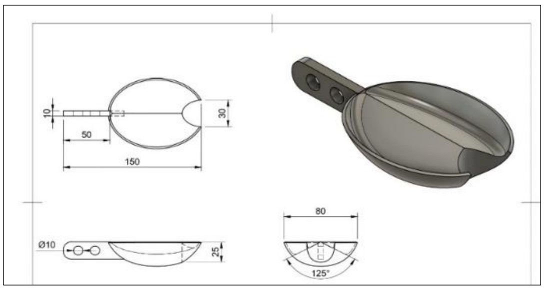

Figure 8. Angle splitter 125°

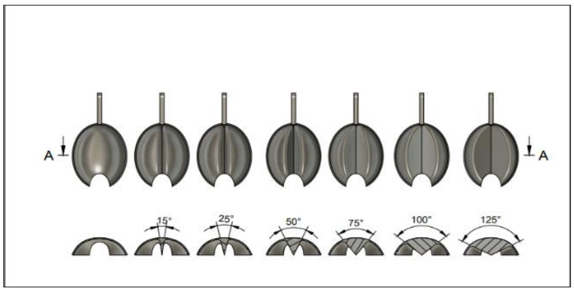

Figure 9. Design of splitter shape

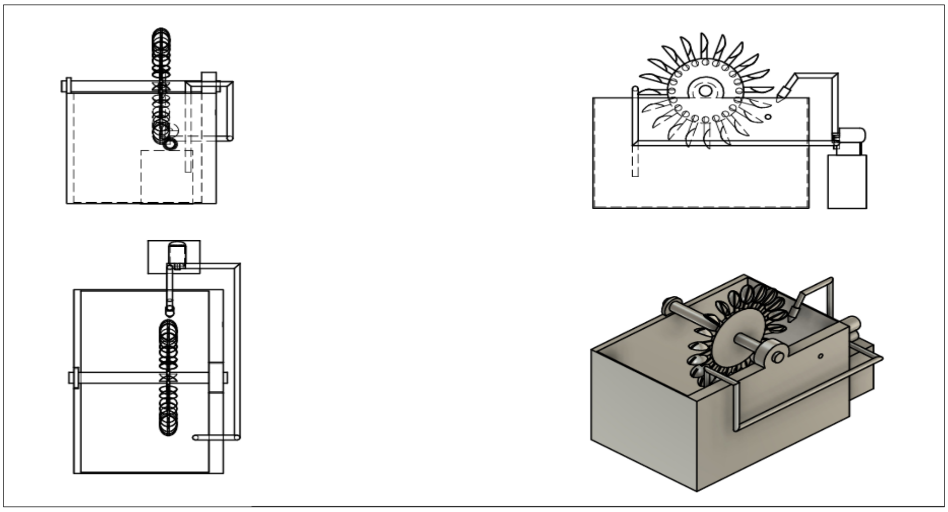

Figure 10. Design of experiment installation

Water discharge is the volume of water that flows per unit time. Water discharge can be used to calculate the flow velocity in each experimental pipe, as determined by Equation 1 [15].

$$\mathrm{Q} = \frac{\mathrm{V}}{\mathrm{t}} \tag{1}$$

Water flow velocity is the amount of water flowing at a certain speed per unit of time. Flow velocity can be determined using Equation 2 [16].

$$\mathrm{v} = \frac{\mathrm{Q}}{\mathrm{A}} \tag{2}$$

Water power is the power entering the nozzle, which can be obtained using Equation 3 [17].

$$P_w = \frac{1}{2}\, \rho\, Q\, v^2 \tag{3}$$

Torque is the rotational force generated by the turbine shaft or the turbine's ability to perform work. Torque is usually symbolized by τ. To find the torque value, Equation 4 can be used [18].

$$\tau = \mathrm{F} \times \mathrm{r} = \mathrm{m} \times \mathrm{g} \times \mathrm{r} \tag{4}$$

The power generated by the turbine, based on torque and rotational speed, is given by Equation 5 [19,20].

$$\mathrm{P_{turbine}} = \tau \times \omega \tag{5}$$

Turbine efficiency is the ratio between the power generated at the turbine shaft and the power supplied by the fluid (water). Turbine efficiency indicates the turbine's ability to convert fluid energy into useful energy at the turbine shaft. Equation 6 is used to determine turbine efficiency [21].

$$\eta_{\mathrm{turbine}} = \frac{\mathrm{P_{turbine}}}{\mathrm{P_{water}}} \times 100\% \tag{6}$$

3 Result and Discussion

At a flow rate of 0.000692 m^3/s, the graph shows that increasing the load from 0.2 kg to approximately 2 kg causes the turbine efficiency to progressively increase across all splitter angle variations and then decrease again after surpassing that point, indicating the presence of a best efficiency point at a load of 2.0 kg as shown in Figure 11 and Table 1. Variations in the splitter angle have been proven to significantly affect the turbine performance, with the 50° angle producing the highest efficiency of approximately 89.12%, compared to the configuration without a splitter at 74.11%, a 15° splitter at 79.74%, and a 25° splitter at 83.49%. These results demonstrate an increase in efficiency of around 13–15%. This improvement indicates that a 50° angle can optimize the jet's distribution and direction, resulting in more effective momentum transfer to the blades. However, at larger angles, namely 75°, 100°, and 125°, the respective efficiencies were 85.99%, 80.99%, and 77.55%, and these values tended to decrease, which was suspected to result from flow separation and increased hydrodynamic losses. The pattern of declining efficiency at higher loads is caused by reduced rotational speed under excessive torque, which decreases output power even though the incoming hydraulic power remains constant. Thus, at a flow rate of 0.000692 m^3/s, the 50° splitter configuration is optimal, providing the most effective energy conversion.

Table 1. Turbine efficiency with load for splitter angle variations at discharge of 0.000692 m^3/s

Load (kg)	Efficiency (%)						
	No Splitter	Splitter 15°	Splitter 25°	Splitter 50°	Splitter 75°	Splitter 100°	Splitter 125°
0.2	10.25	10.82	11.19	11.75	11.44	10.94	10.60
0.4	20.26	21.39	22.14	23.26	22.64	21.64	20.95
0.6	30.02	31.71	32.83	34.52	33.58	32.08	31.05
0.8	39.52	41.78	43.28	45.53	44.28	42.28	40.90
1	48.31	51.13	53.00	55.82	54.25	51.75	50.03
1.2	57.79	61.16	63.42	66.79	64.92	61.91	59.85
1.4	63.48	67.42	70.05	73.99	71.80	68.29	65.89
1.6	67.54	72.05	75.05	79.55	77.05	73.05	70.30
1.8	71.77	76.83	80.21	85.28	82.46	77.96	74.86
2	74.11	79.74	83.49	89.12	85.99	80.99	77.55
2.2	69.14	75.33	79.46	85.65	82.21	76.71	72.92
2.4	66.04	72.80	77.30	84.06	80.30	74.30	70.17
2.6	60.16	67.48	72.36	79.68	75.61	69.11	64.64
2.8	47.72	55.60	60.85	68.73	64.35	57.35	52.53
3	31.42	39.87	45.50	53.94	49.25	41.74	36.58

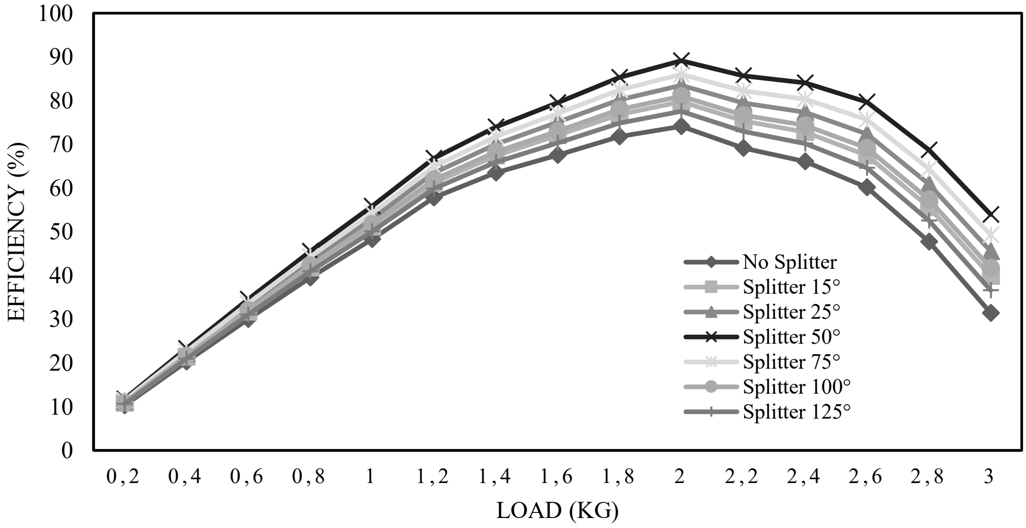

Figure 11. Relationship of turbine efficiency and load for 7 variations of splitter angle at a flow rate of 0.000692 m^3/s

At a discharge of 0.000663 m^3/s, all variations of the splitter angle show a similar trend in characteristics, namely, the efficiency increases gradually as the load rises from 0.2 kg until reaching an optimum point in the range of 1.8–2.0 kg, then decreases at higher loads owing to a reduction in rotational speed caused by the increased load, as shown in Figure 12 and Table 2. The configuration without a splitter yielded the lowest efficiency across the entire load range, with a maximum of approximately 65–67%, indicating an inferior jet distribution and relatively high splash losses. The addition of a 15° splitter increased efficiency to approximately 70–72% at the optimum load, indicating a moderate improvement in flow control, whereas a 25° angle yielded a further increase to 73–75% due to more evenly distributed momentum across the blades. The 50° angle once again becomes the most effective configuration, with a peak efficiency of approximately 83–85%, indicating that at this discharge, this angle maximizes momentum transfer while minimizing turbulence and backflow. The 75° and 100° splitters still performed better than the configuration without a splitter, with maximum efficiencies of approximately 78–80% and 75–77%, respectively. However, there were signs of declining effectiveness owing to potential flow separation at these larger angles. At an angle of 125°, the efficiency decreased again to approximately 72–74%, indicating that a large deviation in angle increased hydrodynamic losses.

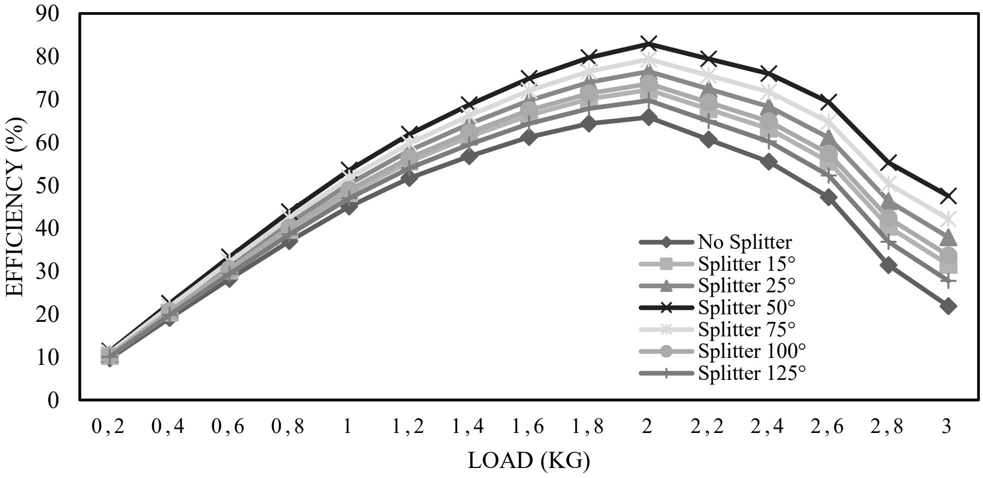

Figure 12. Relationship of turbine efficiency and load for 7 variations of splitter angle at a flow rate of 0.000663 m^3/s

Table 2. Turbine efficiency with load for splitter angle variations at discharge of 0.000662 m^3/s

Load (kg)	Efficiency (%)						
	No Splitter	Splitter 15°	Splitter 25°	Splitter 50°	Splitter 75°	Splitter 100°	Splitter 125°
0.2	9.67	10.31	10.74	11.38	11.02	10.46	10.06
0.4	19.07	20.35	21.20	22.48	21.77	20.63	19.85
0.6	28.17	30.10	31.38	33.30	32.23	30.52	29.35
0.8	37.00	39.56	41.27	43.83	42.41	40.13	38.56
1	45.00	48.21	50.34	53.54	51.76	48.92	46.96
1.2	51.66	55.50	58.06	61.90	59.77	56.35	54.01
1.4	56.78	61.26	64.25	68.74	66.25	62.26	59.52
1.6	61.19	66.32	69.73	74.86	72.01	67.46	64.32
1.8	64.36	70.12	73.97	79.73	76.53	71.40	67.88
2	65.82	72.22	76.49	82.90	79.34	73.65	69.73
2.2	60.66	67.70	72.40	79.45	75.53	69.27	64.96
2.4	55.50	63.19	68.31	75.99	71.73	64.89	60.20
2.6	47.17	55.50	61.05	69.38	64.75	57.35	52.26
2.8	31.38	40.34	46.32	55.29	50.31	42.34	36.86
3	21.88	31.48	37.89	47.49	42.16	33.62	27.75

At a constant discharge of 0.000642 m³/s, all splitter angle variations show a consistent pattern of increasing efficiency as the load rises from 0.2 kg to reach an optimum point in the range of 1.8–2.0 kg, and then experience a decline at higher loads due to reduced rotational speed and increased mechanical and hydrodynamic losses, as shown in Figure 13 and Table 3. The configuration without a splitter yielded the lowest efficiency, with a maximum value of approximately 54.68%, indicating that the jet distribution to the blades was not yet optimal and that losses still occurred owing to splashing and backflow. Adding a 15° splitter raised the peak efficiency to approximately 61.71%, indicating improved flow-direction control, whereas a 25° splitter increased it to 66.39% because the momentum was distributed more evenly across the blades. The 50° angle again demonstrated the best performance, with a maximum efficiency of around 73.43% at a load of ±2 kg, confirming that this configuration is the most effective in optimizing the transfer of kinetic energy into mechanical energy and minimizing internal turbulence. The 75° splitter produced a peak efficiency of around 69.52%, which was slightly lower than that of the 50° splitter but still higher than that of the smaller angles, whereas the 100° splitter showed a maximum efficiency of approximately 63.27%, indicating the onset of increased losses owing to potential flow separation. At a 125° angle, the efficiency dropped again to approximately 58.97%, indicating that an excessively large angle reduced the effectiveness of the jet-blade interaction and increased hydrodynamic losses. The significant efficiency decline at loads above 2.4 kg across all variations indicates that the turbine operates beyond its optimal efficiency point, leading to a decrease in output power even though input hydraulic power remains constant. Overall, at a discharge of 0.000642 m³/s, the 50° splitter angle was the most optimal configuration, as it yielded the highest efficiency and displayed the most stable performance characteristics compared with the other angle variations.

Table 3. Turbine efficiency with load for splitter angle variations at discharge of 0.000642 m^3/s

Load (kg)	Efficiency (%)						
	No Splitter	**Splitter 15°**	**Splitter 25°**	**Splitter 50°**	**Splitter 75°**	**Splitter 100°**	**Splitter 125°**
0.2	8.86	9.56	10.03	10.74	10.35	9.72	9.29
0.4	17.42	18.82	19.76	21.16	20.38	19.13	18.27
0.6	25.66	27.77	29.17	31.28	30.11	28.23	26.95
0.8	33.59	36.40	38.27	41.08	39.52	37.02	35.30
1	40.62	44.13	46.47	49.99	48.04	44.91	42.76
1.2	46.16	50.38	53.19	57.41	55.07	51.32	48.74
1.4	51.12	56.04	59.33	64.25	61.51	57.14	54.13
1.6	53.11	58.74	62.49	68.11	64.99	59.99	56.55
1.8	54.83	61.16	65.38	71.71	68.19	62.57	58.70
2	54.68	61.71	66.39	73.43	69.52	63.27	58.97
2.2	51.55	59.29	64.44	72.18	67.88	61.00	56.28
2.4	43.12	51.55	57.18	65.61	60.93	53.43	48.27
2.6	37.57	46.71	52.80	61.94	56.86	48.74	43.15
2.8	20.77	30.62	37.18	47.02	41.55	32.80	26.79
3	9.96	20.50	27.53	38.08	32.22	22.84	16.40

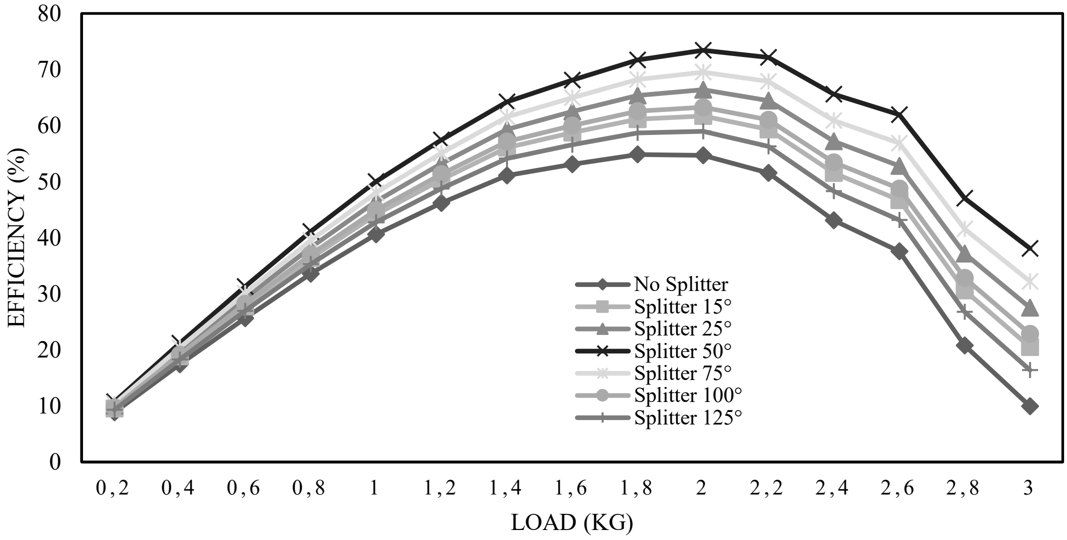

Figure 13. Relationship of turbine efficiency and load for 7 variations of splitter angle at a flow rate of 0,000642 m^3/s

At a constant flow rate of 0.000623 m³/s, all splitter angle configurations showed a characteristic efficiency pattern that increased as the load rose from 0.2 kg to reach an optimum point in the range of 1.8–2.0 kg, and then began to decrease at a load of 2.2 kg due to a drop in rotational speed and increased mechanical and hydrodynamic losses, as shown in Figure 14 and Table 4. The configuration without a splitter yielded the lowest performance, with a maximum efficiency of approximately 47.71%, indicating that without a flow guide, the jet distribution to the blades was less than optimal, and losses due to splashing and backflow were relatively high.

Table 4. Turbine efficiency with load for splitter angle variations at discharge of 0.000623 m^3/s

Load (kg)	**Efficiency (%)**						
	No Splitter	**Splitter 15°**	**Splitter 25°**	**Splitter 50°**	**Splitter 75°**	**Splitter 100°**	**Splitter 125°**
0.2	8.33	9.10	9.62	10.38	9.96	9.27	8.80
0.4	16.33	17.87	18.89	20.43	19.58	18.21	17.27
0.6	23.98	26.29	27.83	30.14	28.86	26.80	25.39
0.8	31.98	35.06	37.11	40.19	38.48	35.74	33.86
1	37.62	41.47	44.03	47.88	45.74	42.32	39.97
1.2	42.32	46.94	50.02	54.64	52.07	47.97	45.15
1.4	45.19	50.58	54.17	59.55	56.56	51.77	48.48
1.6	47.20	53.36	57.46	63.62	60.20	54.72	50.96
1.8	47.71	54.64	59.26	66.18	62.33	56.18	51.94
2	46.17	53.87	59.00	66.70	62.42	55.58	50.88
2.2	41.38	49.85	55.49	63.96	59.26	51.73	46.56
2.4	32.32	41.55	47.71	56.95	51.82	43.61	37.96
2.6	25.01	35.01	41.68	51.69	46.13	37.24	31.12
2.8	3.59	14.36	21.54	32.32	26.33	16.76	10.17
3	0.00	1.28	8.97	20.52	14.10	3.84	0.00

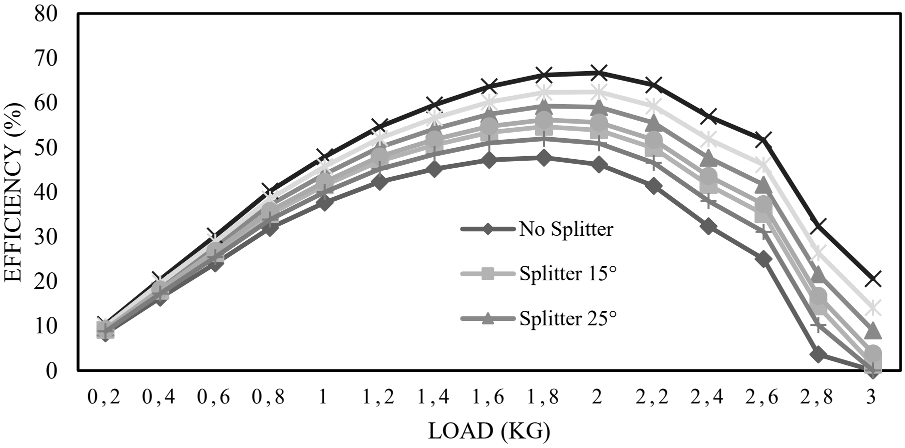

Figure 14. Relationship of turbine efficiency and load for 7 variations of splitter angle at a flow rate of 0.000623 m^3/s

Adding a 15° splitter increased efficiency to approximately 54.64%, indicating an initial improvement in flow direction control, whereas a 25° splitter increased efficiency to 59.26% because momentum was distributed more evenly across the blades. The 50° angle once again delivered the best performance, with a peak efficiency of around 66.70%, indicating that at this flow rate, it was most effective at maximizing momentum transfer and minimizing internal turbulence. The 75° splitter achieved a maximum efficiency of approximately 62.42%, slightly lower than that of the 50° splitter but still better than the smaller angles, whereas the 100° splitter showed a tendency toward decreased performance to 56.18% owing to the onset of flow separation. At an angle of 125°, the maximum efficiency drops further to approximately 51.94%, indicating that excessively large angles lead to increased energy losses and reduced effectiveness of the jet-blade interaction.

At a constant flow rate of 0.000692 m^3/s, the relationship between the load and turbine power showed a progressive increase from a load of 0.2 kg to a maximum power in the range of 1.8–2.0 kg, and then decreased at higher loads owing to the reduced rotational speed and increased mechanical resistance as shown in Table 5, Table 6, and Figure 15.

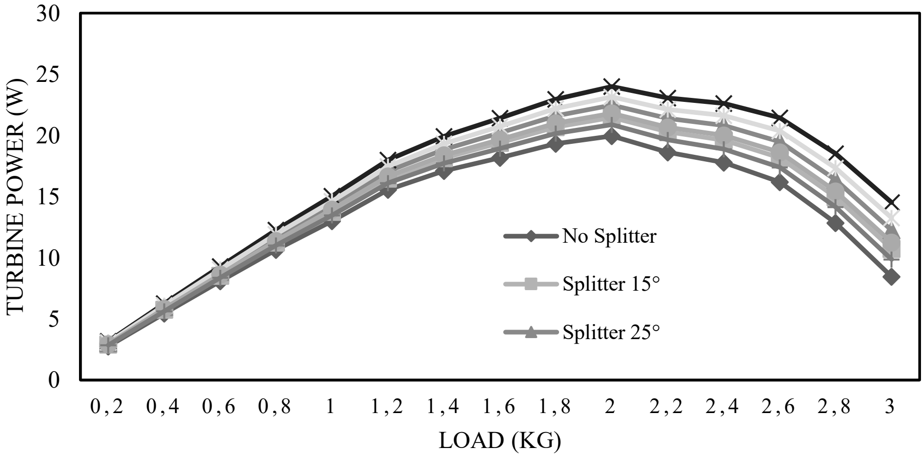

Figure 15. Relationship of turbine power and load for 7 variations of splitter angle at a flow rate of 0.000692 m^3/s

Table 5. Turbine power with load for splitter angle variations at discharge of 0.000692 m^3/s

Load (kg)	Turbine power (W)						
	No Splitter	Splitter 15°	Splitter 25°	Splitter 50°	Splitter 75°	Splitter 100°	Splitter 125°
0.2	2.76	2.91	3.01	3.16	3.08	2.94	2.85
0.4	5.45	5.75	5.96	6.26	6.09	5.82	5.64
0.6	8.08	8.53	8.84	9.29	9.04	8.63	8.36
0.8	10.64	11.24	11.65	12.25	11.92	11.38	11.01
1	13.00	13.76	14.27	15.02	14.60	13.93	13.47
1.2	15.55	16.46	17.07	17.98	17.47	16.67	16.11
1.4	17.09	18.15	18.85	19.92	19.33	18.38	17.74
1.6	18.18	19.39	20.20	21.41	20.74	19.66	18.92
1.8	19.32	20.68	21.59	22.96	22.20	20.99	20.15
2	19.95	21.47	22.48	24	23.15	21.80	20.88
2.2	18.61	20.28	21.39	23.06	22.13	20.65	19.63
2.4	17.78	19.60	20.81	22.63	21.62	20.00	18.89
2.6	16.19	18.16	19.48	21.45	20.35	18.60	17.40
2.8	12.84	14.97	16.38	18.50	17.32	15.44	14.14
3	8.46	10.73	12.25	14.52	13.26	11.24	9.85

Table 6. Turbine rotation for splitter angle variations at discharge of 0.000692 m^3/s

Load (kg)	Turbine rotation (rpm)						
	No Splitter	Splitter 15°	Splitter 25°	Splitter 50°	Splitter 75°	Splitter 100°	Splitter 125°
0.2	328	346	358	376	366.0	350	339
0.4	324	342	354	372	362.0	346	335
0.6	320	338	350	368	358.0	342	331
0.8	316	334	346	364	354.0	338	327
1	309	327	339	357	347.0	331	320
1.2	308	326	338	356	346.0	330	319
1.4	290	308	320	338	328.0	312	301
1.6	270	288	300	318	308.0	292	281
1.8	255	273	285	303	293.0	277	266
2	237	255	267	285	275.0	259	248
2.2	201	219	231	249	239.0	223	212
2.4	176	194	206	224	214.0	198	187
2.6	148	166	178	196	186.0	170	159
2.8	109	127	139	157	147.0	131	120
3	67	85	97	115	105	89	78

The configuration without a splitter produced the lowest power across the entire load range, with a peak power of approximately 19.95 W, indicating that without a flow guide, the momentum transfer from the jet to the blades was not yet optimal. Adding a 15° splitter increased the maximum power to approximately 21.47 W, whereas a 25° splitter increased it further to 22.48 W, indicating improved flow distribution and fluid–blade interaction. The 50° angle yielded the best performance, with a peak power of approximately 24 W at a 2 kg load, confirming that this angle is the most effective at directing the jet so that the kinetic energy is converted to mechanical energy at the maximum rate.

The 75° and 100° splitters produced maximum powers of approximately 23.15 W and 21.80 W, respectively, which were still higher than those without a splitter but slightly lower than the value at the 50° angle, indicating reduced effectiveness due to potential additional turbulence. At a flow rate of 0.000663 m³/s, the turbine power curve against load variations showed a gradual increase from a load of 0.2 kg, reaching a maximum in the range of 1.8–2.0 kg, and then experiencing a decline at higher loads owing to the dominance of load over the steady power, as shown in Figure 16, Table 7, and Table 8.

Table 7. Turbine power with load for splitter angle variations at discharge of 0.000663 m^3/s

Load (kg)	**Turbine power (W)**						
	No Splitter	**Splitter 15°**	**Splitter 25°**	**Splitter 50°**	**Splitter 75°**	**Splitter 100°**	**Splitter 125°**
0.2	2.29	2.44	2.54	2.69	2.61	2.47	2.38
0.4	4.51	4.81	5.01	5.32	5.15	4.88	4.69
0.6	6.66	7.12	7.42	7.88	7.62	7.22	6.94
0.8	8.75	9.36	9.76	10.37	10.03	9.49	9.12
1	10.65	11.40	11.91	12.67	12.25	11.57	11.11
1.2	12.22	13.13	13.74	14.65	14.14	13.33	12.78
1.4	13.43	14.49	15.20	16.26	15.67	14.73	14.08
1.6	14.48	15.69	16.50	17.71	17.04	15.96	15.22
1.8	15.23	16.59	17.50	18.86	18.11	16.89	16.06
2	15.57	17.09	18.10	19.61	18.77	17.42	16.50
2.2	14.35	16.02	17.13	18.80	17.87	16.39	15.37
2.4	13.13	14.95	16.16	17.98	16.97	15.35	14.24
2.6	11.16	13.13	14.44	16.41	15.32	13.57	12.36
2.8	7.42	9.54	10.96	13.08	11.90	10.01	8.72
3	5.17	7.45	8.96	11.24	9.97	7.95	6.56

Table 8. Turbine rotation for splitter angle variations at discharge of 0.000663 m^3/s

Load (kg)	**Turbine rotation (rpm)**						
	No Splitter	**Splitter 15°**	**Splitter 25°**	**Splitter 50°**	**Splitter 75°**	**Splitter 100°**	**Splitter 125°**
0.2	272	290	302	320	310.0	294	283
0.4	268	286	298	316	306.0	290	279
0.6	264	282	294	312	302.0	286	275
0.8	260	278	290	308	298.0	282	271
1	253	271	283	301	291.0	275	264
1.2	242	260	272	290	280.0	264	253
1.4	228	246	258	276	266.0	250	239
1.6	215	233	245	263	253.0	237	226
1.8	201	219	231	249	239.0	223	212
2	185	203	215	233	223.0	207	196
2.2	155	173	185	203	193.0	177	166
2.4	130	148	160	178	168.0	152	141
2.6	102	120	132	150	140.0	124	113
2.8	63	81	93	111	101.0	85	74

3	41	59	71	89	79	63	52

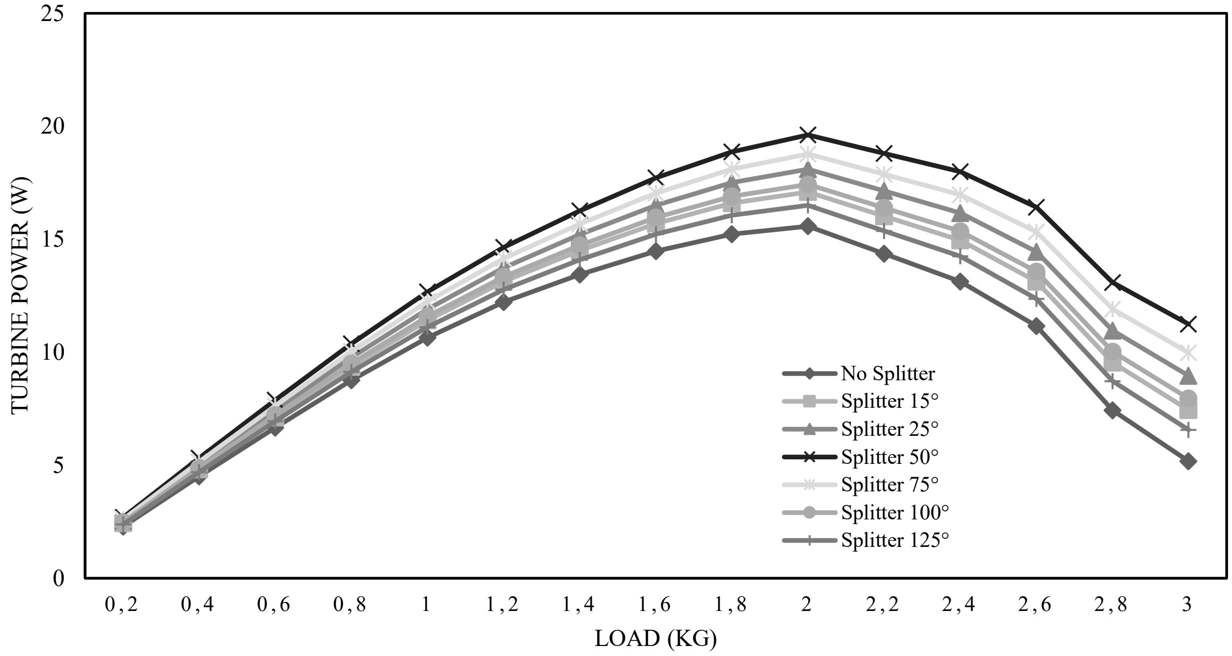

Figure 16. Relationship of Turbine power and Load for 7 Variations of Splitter Angle at a Flow Rate of 0.000663 m^3/s

The configuration without a splitter produced the lowest power across the entire testing range, with a peak power of approximately 15.57 W, indicating that, without a flow guide, momentum transfer from the jet to the blades was suboptimal. The addition of a 15° splitter increased the maximum power to approximately 17.09 W, indicating improved flow distribution, whereas a 25° splitter increased it further to 18.10 W as the fluid–blade interaction became more effective. The 50° angle once again demonstrated the best performance, with a peak power of approximately 19.61 W at a 2 kg load, confirming that this configuration was the most effective at converting kinetic energy to mechanical energy. The 75° and 100° splitters produced maximum powers of approximately 18.77 W and 17.42 W, respectively, which were higher than those without a splitter but slightly lower than the value at the 50° angle, indicating increased losses due to potential turbulence or flow separation at larger angles. At 125°, the maximum power decreased to approximately 16.50 W.

At a flow rate of 0.000642 m^3/s, the turbine power characteristics in response to varying loads showed a gradual increase from a load of 0.2 kg, reaching maximum power in the range of 1.8–2.0 kg, and then experiencing a significant decrease at higher loads owing to the reduced rotational speed and increased mechanical losses, as shown in Figure 17, Table 9, and Table 10. The configuration without a splitter produced the lowest power across the entire test range, with a peak power of approximately 11.82 W, indicating that without a flow director, the momentum transfer from the jet to the blades was not yet optimal and that some energy was lost to splashing and backflow. Adding a 15° splitter increased the maximum power to approximately 13.30 W, suggesting improved flow distribution, whereas a 25° splitter increased it further to 14.31 W, as the interaction between the jet and blades became more effective. The 50° angle again shows the best performance, with a peak power of approximately 15.82 W at a load of 2 kg, confirming that this configuration is optimal for directing the jet to maximize the conversion of kinetic energy into mechanical energy.

The 75° splitter produced a maximum power of approximately 14.98 W, slightly lower than the 50° splitter but still higher than the smaller angles, whereas the 100° splitter showed a peak power of approximately 13.63 W, indicating increasing losses due to potential turbulence and flow separation. At a 125° angle, the maximum power dropped again to approximately 12.71 W, indicating that an excessively large angle reduces the effectiveness of energy transfer.

Table 9. Turbine power with load for splitter angle variations at discharge of 0.000642 m^3/s

Load (kg)	Turbine power (W)						
	No Splitter	**Splitter 15°**	**Splitter 25°**	**Splitter 50°**	**Splitter 75°**	**Splitter 100°**	**Splitter 125°**
0.2	1.91	2.06	2.16	2.31	2.23	2.09	2.00
0.4	3.75	4.05	4.26	4.56	4.39	4.12	3.94
0.6	5.53	5.98	6.28	6.74	6.49	6.08	5.80
0.8	7.24	7.84	8.25	8.85	8.52	7.98	7.61
1	8.75	9.51	10.01	10.77	10.35	9.68	9.21
1.2	9.95	10.86	11.46	12.37	11.87	11.06	10.50
1.4	11.02	12.08	12.78	13.85	13.26	12.31	11.66
1.6	11.45	12.66	13.47	14.68	14.01	12.93	12.19
1.8	11.82	13.18	14.09	15.45	14.70	13.48	12.65
2	11.78	13.30	14.31	15.82	14.98	13.63	12.71
2.2	11.11	12.78	13.89	15.55	14.63	13.15	12.13
2.4	9.29	11.11	12.32	14.14	13.13	11.51	10.40
2.6	8.09	10.06	11.38	13.35	12.25	10.50	9.30
2.8	4.47	6.60	8.01	10.13	8.95	7.07	5.77
3	2.14	4.42	5.93	8.20	6.94	4.92	3.53

Table 10. Turbine rotation for splitter angle variations at discharge of 0.000642 m^3/s

Load (kg)	Turbine rotation (rpm)						
	No Splitter	**Splitter 15°**	**Splitter 25°**	**Splitter 50°**	**Splitter 75°**	**Splitter 100°**	**Splitter 125°**
0.2	227	245	257	275	265.0	249	238
0.4	223	241	253	271	261.0	245	234
0.6	219	237	249	267	257.0	241	230
0.8	215	233	245	263	253.0	237	226
1	208	226	238	256	246.0	230	219
1.2	197	215	227	245	235.0	219	208
1.4	187	205	217	235	225.0	209	198
1.6	170	188	200	218	208.0	192	181
1.8	156	174	186	204	194.0	178	167
2	140	158	170	188	178.0	162	151
2.2	120	138	150	168	158.0	142	131
2.4	92	110	122	140	130.0	114	103
2.6	74	92	104	122	112.0	96	85
2.8	38	56	68	86	76.0	60	49

3	17	35	47	65	55	39	28

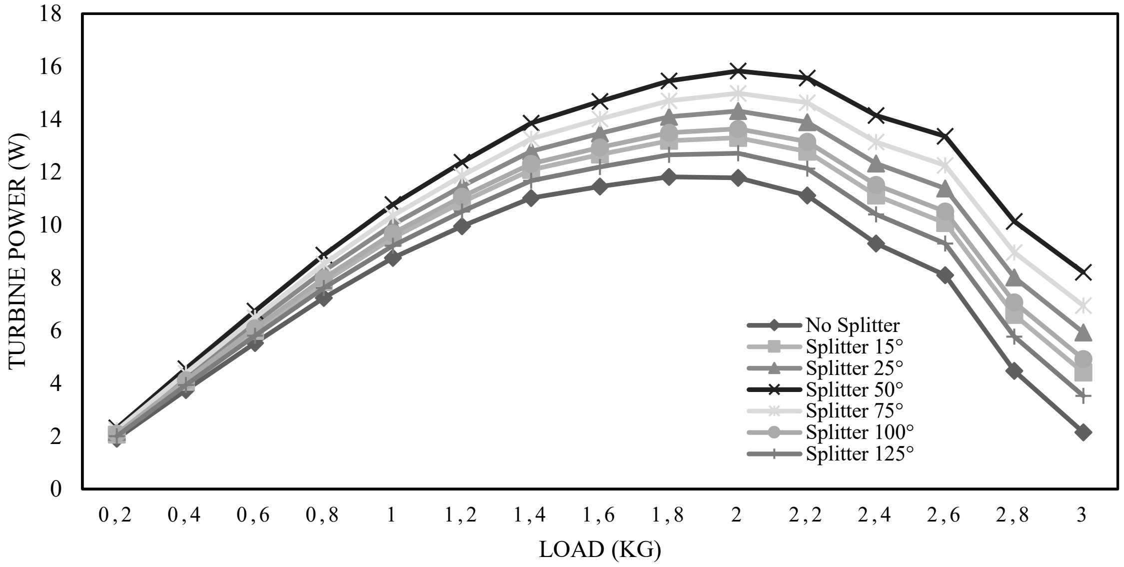

Figure 17. Relationship of Turbine power and load for 7 variations of splitter angle at a flow rate of 0.000642 m^3/s.

At a discharge of 0.000623 m³/s, the relationship between load and turbine power showed a gradual increase from a load of 0.2 kg as shown in Figure 18, Table 11 and Table 12 reaching maximum power in the range of 1.8–2.0 kg, and then experiencing a sharp decline at loads above 2.4 kg owing to the reduced rotational speed and the dominance of load torque over the constant incoming hydraulic power. The configuration without a splitter produced the lowest power across the entire test range, with a peak power of approximately 9.39 W, indicating that without a flow guide, jet distribution to the blades was less effective, and significant energy losses occurred. The addition of a 15° splitter increased the maximum power to approximately 10.76 W, indicating an initial improvement in flow-direction control, whereas a 25° splitter further increased it to 11.66 W due to a more uniform momentum distribution on the blade surface. The 50° angle showed the best performance, with a peak power of approximately 13.13 W at a 2 kg load, confirming that this angle is optimal for directing the jet to maximize the transfer of kinetic energy to mechanical energy. The 75° splitter achieved a maximum power of approximately 12.29 W, which was slightly lower than that of the 50° splitter but still better than that of the smaller angles, whereas the 100° splitter yielded a peak power of approximately 11.06 W, indicating increased losses, likely due to turbulence or flow separation.

Table 11. Turbine power with load for splitter angle variations at discharge of 0.000623 m^3/s

Load (kg)	**Turbine power (W)**						
	No Splitter	**Splitter 15°**	**Splitter 25°**	**Splitter 50°**	**Splitter 75°**	**Splitter 100°**	**Splitter 125°**
0.2	1.64	1.79	1.89	2.04	1.96	1.82	1.73
0.4	3.21	3.51	3.72	4.02	3.85	3.58	3.40
0.6	4.72	5.17	5.48	5.93	5.68	5.27	5.00
0.8	6.29	6.90	7.30	7.91	7.57	7.03	6.66
1	7.40	8.16	8.67	9.42	9.00	8.33	7.87
1.2	8.33	9.24	9.85	10.76	10.25	9.44	8.89

1.4	8.89	9.96	10.66	11.72	11.13	10.19	9.54

.**Table 11.** *Cont.*

Load (kg)	Turbine power (W)						
	No Splitter	Splitter 15°	Splitter 25°	Splitter 50°	Splitter 75°	Splitter 100°	Splitter 125°
1.6	9.29	10.50	11.31	12.52	11.85	10.77	10.03
1.8	9.39	10.76	11.66	13.03	12.27	11.06	10.22
2	9.09	10.60	11.61	13.13	12.29	10.94	10.01
2.2	8.15	9.81	10.92	12.59	11.66	10.18	9.16
2.4	6.36	8.18	9.39	11.21	10.20	8.58	7.47
2.6	4.92	6.89	8.20	10.17	9.08	7.33	6.12
2.8	0.70	2.82	4.24	6.36	5.18	3.30	2.00
3	0.00	0.25	1.76	4.04	2.77	0.75	0.00

Table 12. Turbine rotation for splitter angle variations at discharge of 0.000623 m^3/s.

Load (kg)	Turbine rotation (rpm)						
	No Splitter	Splitter 15°	Splitter 25°	Splitter 50°	Splitter 75°	Splitter 100°	Splitter 125°
0.2	195	213	225	243	233.0	217	206
0.4	191	209	221	239	229.0	213	202
0.6	187	205	217	235	225.0	209	198
0.8	187	205	217	235	225.0	209	198
1	176	194	206	224	214.0	198	187
1.2	165	183	195	213	203.0	187	176
1.4	151	169	181	199	189.0	173	162
1.6	138	156	168	186	176.0	160	149
1.8	124	142	154	172	162.0	146	135
2	108	126	138	156	146.0	130	119
2.2	88	106	118	136	126.0	110	99
2.4	63	81	93	111	101.0	85	74
2.6	45	63	75	93	83.0	67	56
2.8	6	24	36	54	44.0	28	17
3	0	2	14	32	22	6	0

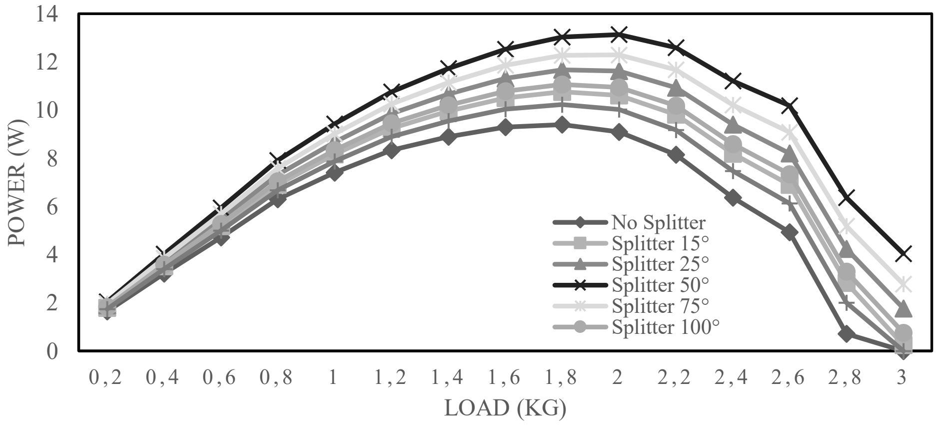

Figure 18. Relationship of Turbine power and load for 7 variations of splitter angle at a flow rate of 0.000623 m^3/s

At 125°, the maximum power dropped again to approximately 10.22 W, indicating that a large angle reduced the effectiveness of the jet-blade interaction. The significant power drop at the maximum load of 2.8–3 kg for all variations indicates that the turbine is operating far from its optimum point, resulting in a drastic decrease in the angular velocity and output power. The results show a relation between splitter angle and efficiency and turbine power. The water discharge is 0.000692 m^3/s, 0.000663 m^3/s, 0.000642 m^3/s, and 0.000623 m^3/s. Figure 19 and Table 13 below explain that a splitter angle of 500 creates the highest efficiency and turbine power.

Table 13. Highest efficiency on various discharge

Discharge (m^3/s)	**Efficiency**						
	No Splitter	**Splitter 15°**	**Splitter 25°**	**Splitter 50°**	**Splitter 75°**	**Splitter 100°**	**Splitter 125°**
0.000623	46.18	53.87	59.00	66.70	62.42	55.58	50.88
0.000642	54.68	61.71	66.40	73.43	69.52	63.28	58.98
0.000663	65.82	72.23	76.50	82.90	79.34	73.65	69.74
0.000692	74.12	79.74	83.50	89.13	86.00	81.00	77.56

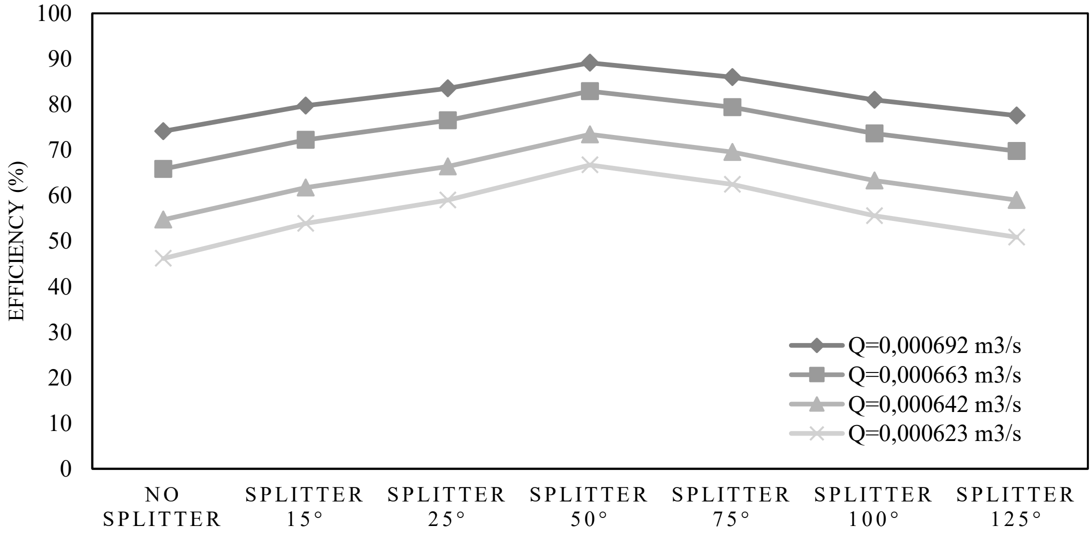

Figure 19. Relationship Splitter Angle and Turbine Efficiency

At splitter angles of 15° and 25°, the efficiency was between 70-80%, while the 75° splitter showed better results than the 100° and 125° splitters. However, the 50° splitter exhibited the highest efficiency among all splitter angles and the case without a splitter. This is because the 50-degree angle promotes a stable distribution of flow to the turbine blades, with water following the blade contours, thereby reducing vibration and friction. It also delayed flow separation and minimized flow turbulence at the blades. It is also clear that the use of splitters significantly affects turbine performance. Splitters at 15° and 25° produced higher friction forces because flow separation was delayed due to the smaller splitter angle. This high friction causes vibrations, which reduce the momentum transfer from the water jet to the blade. Lower energy conversion reduces efficiency because the water's kinetic energy is not fully converted into shaft work. Splitter 50 showed a fairly good performance compared to splitters 15°, 25°, 75°, and 100°. Splitters at 100° and 125° showed decreased efficiency because the splitter angle was too wide, causing flow separation to occur too quickly and creating a reverse force from water splashes. In addition, these splashes reduce the effective discharge available to rotate the shafts. Another cause is turbulence due to a high initial impact, resulting in significant energy loss. Previous research stated that a sharp splitter design can improve efficiency compared to a blunt splitter design [14]. The difference in turbine efficiency at the highest discharge between the no-splitter and the 50° splitter was 74.12% and 89.13%, respectively; thus, there was an increase in efficiency of approximately 15%, or 20%. The graph in Figure 20 and Table 14 shows the relationship between the splitter angle on the Pelton turbine blade and the turbine power for the four discharge variations. According to the principles of fluid mechanics, the power of a water turbine is determined by the momentum of the flow transferred from the water jet to the turbine blade. An increase in the splitter angle affected the direction of the flow deflection and the distribution of kinetic energy. The power increases significantly with the splitter angle until it reaches an optimum of approximately 50°, after which it begins to decrease at larger angles. This is in accordance with the impulse-momentum concept, where the deflection angle of the jet determines the magnitude of the momentum change and, consequently, the force received by the blade. At an angle of 50 °, the flow was distributed more evenly along the blade profile, minimizing vibration and significantly reducing water splashing and turbulence. The turbine power with no splitter and with a 50° splitter was 19.95 W and 24 W, respectively, indicating an increase of approximately 4 W (20%) at the maximum flow rate.

Table 14. Highest turbine power on various discharges

Discharge (m^3/s)	Daya						
	No Splitter	Splitter 15°	Splitter 25°	Splitter 50°	Splitter 75°	Splitter 100°	Splitter 125°
0.000623	9.39	10.76	11.66	13.13	12.29	11.06	10.22
0.000642	11.82	13.30	14.31	15.82	14.98	13.63	12.71
0.000663	15.57	17.09	18.10	19.61	18.77	17.42	16.06
0.000692	19.95	21.47	22.48	24	23.15	21.80	20.88

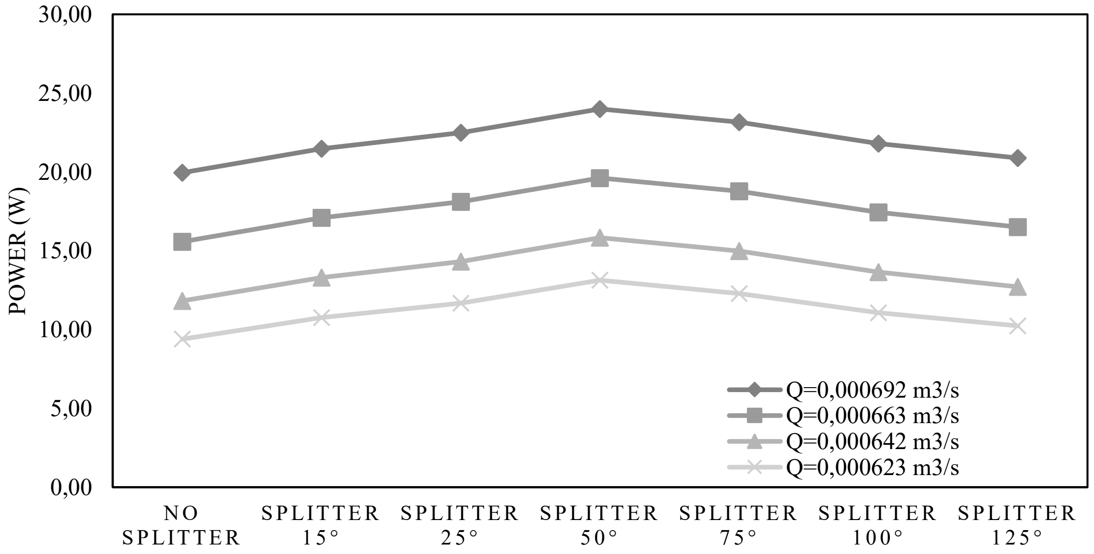

Figure 20. Relationship Splitter Angle and Turbine Power

The differences between the curves indicate the effect of the discharge on the power. The largest discharge of 0.000692 m³/s produced the highest power because the kinetic energy of the flow is directly proportional to the discharge and jet velocity. However, the power pattern with respect to the splitter angle was similar across all discharge variations: maximum power was achieved at a splitter angle of 50°, and power decreased at angles too small or too large. The decrease in power at large angles of 75°, 100°, and 125° was due to increased flow separation and energy loss from higher turbulence, resulting in reduced momentum-transfer efficiency. Thus, the correct splitter angle is crucial for maximizing energy transfer and reducing hydrodynamic losses. A sharper splitter angle produces the greatest impact force, thereby maximizing power output [13]. An optimal splitter angle can increase the power output of Pelton turbines, especially under high-head and low-flow conditions [12].

The results of numerical simulations using ANSYS showed that the velocity contour distributions and jet–blade interaction patterns differed significantly for each splitter-angle variation shown in Figures 21-27. In the configuration without a splitter, the jet tended to concentrate on one side of the blade, with a narrow, high-velocity zone (red–yellow) and a less uniform flow distribution, which could lead to local turbulence and energy losses due to splashing and backflow. The addition of 15° and 25° splitters improved the flow distribution, with the jet becoming more directed and spreading over a larger area of the blade. However, the maximum velocity intensity remained relatively focused and not fully homogeneous. At an angle of 50°, the high-velocity distribution appeared to be the most stable and directed along the blade contour, with a more even spread of momentum and indications of reduced flow separation in the downstream part of the blade. This condition indicates a more effective and coherent momentum transfer between the fluid and the blade surface. Conversely, at larger angles, such as 75°, 100°, and 125°, the contour patterns tended to show jet deviation and sharp velocity gradients in certain areas, indicating the potential for flow separation and increased secondary turbulence. Although the distribution is still better than the case without a splitter, excessively large angles cause part of the jet to fail to follow the blade curvature optimally, thereby increasing hydrodynamic losses. Overall, these numerical visualization results are consistent with the experimental data, which indicate that the 50° angle provides the most effective flow interaction, as evidenced by a more uniform kinetic energy distribution, reduced stagnation zones, and minimized losses, resulting in the highest power performance and efficiency compared to the other angle variations.

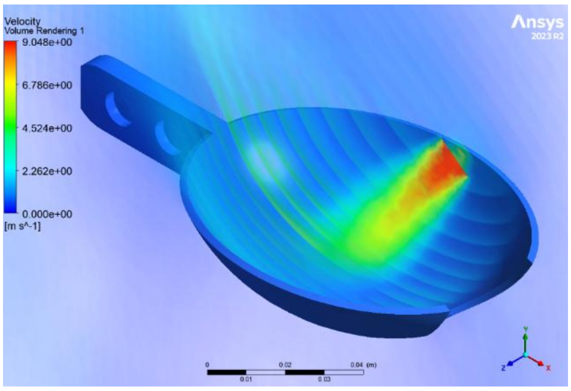

Figure 21. No Splitter

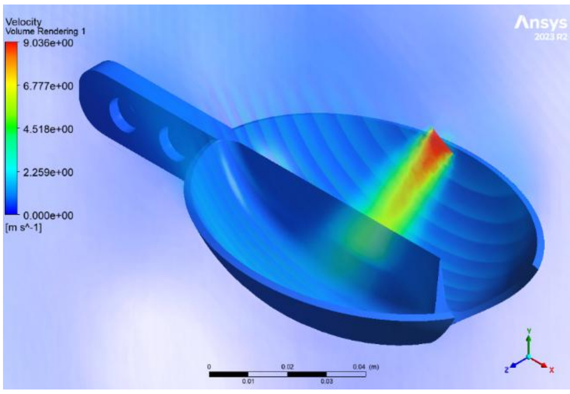

Figure 22. Splitter 15°

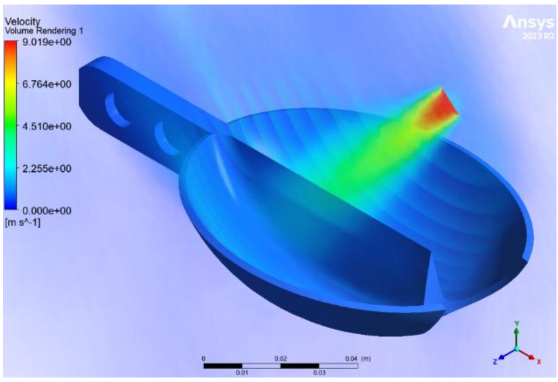

Figure 23. Splitter 25°

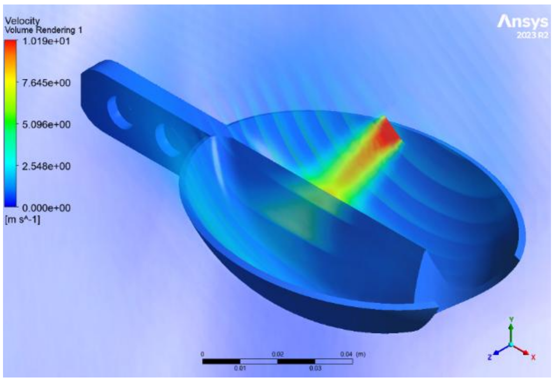

Figure 24. Splitter 50°

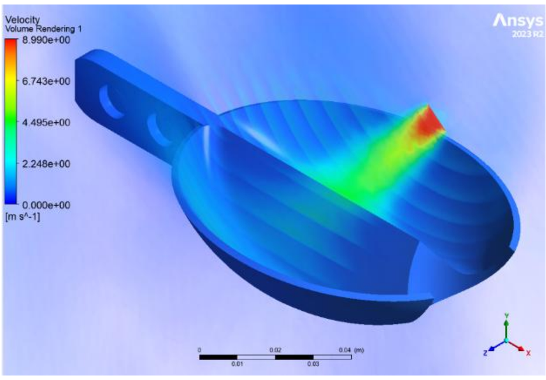

Figure 25. Splitter 75°

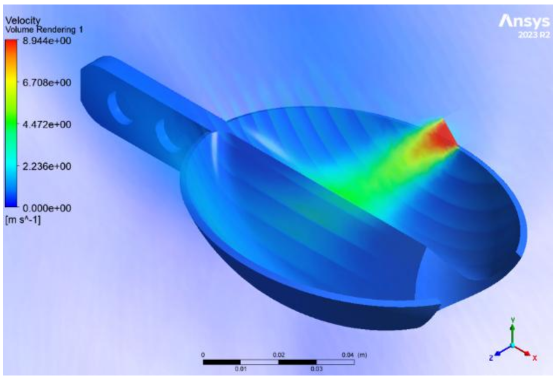

Figure 26. Splitter 100°

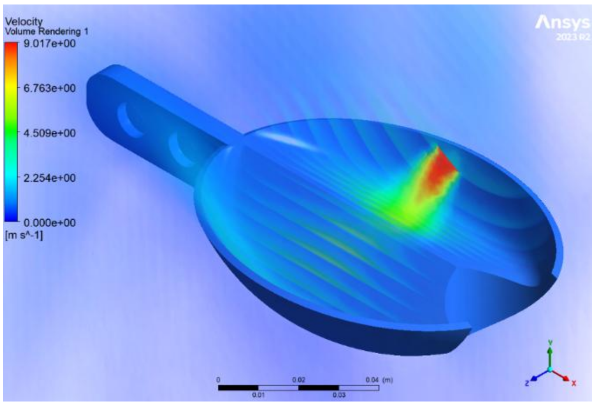

Figure 27. Splitter 125°

4 Conclusions

The results show that the power and efficiency of Pelton turbines are affected by the splitter angle, as it determines the momentum and energy transfer from the water jet to the turbine blade, converting it into mechanical energy in both experimental and simulation methods. A splitter angle of 50° achieved the highest efficiency because it optimally distributed the water jet from the nozzle to the blade, minimizing turbulence in the bucket and increasing efficiency and power by approximately 20% at the highest flow rate compared to the no-splitter condition. The highest efficiency of 89.12% and the highest power of 24 W were obtained at a splitter angle of 50° with a mass load of 2 kg, yielding the highest discharge of 0.000692 m3/s, turbine rotation of 285 rpm, and torque of 0.8044 Nm. The simulation showed the same results as the experiment, in that using a splitter produced positive results compared with the conditions without a splitter. The water flow contours from the nozzle indicate where the water velocity can be maintained at optimal levels and distributed more uniformly and stably.

At the highest discharge, the efficiency achieved was approximately 75% without a splitter and approached approximately 89% with a 50° splitter angle. Splitters at 25° and 75° also show fairly high performance, approximately 85%, but remain slightly below the 50° splitter. In comparison, extreme angles such as 100° and 125° produce lower efficiency, although still better than without a splitter. The turbine power increased significantly compared with the no-splitter case, which produced 20.5 W; the 50° angle produced 24 W, followed by the 25° and 75° splitters, which produced slightly lower power. Splitters with extreme angles, such as 100° and 125°, exhibited lower power than the optimal configuration, yet remained better than the no-splitter configuration.

5 Acknowledgement

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References

[1] M. Idris, M. Weriono, I. Dalil, J. Hermawan, A. J. Zulfikar, and M. Y. Yuhazri, “Water flow simulation in a Pelton turbine bucket with variable bucket dimensions using computational fluid dynamic,” *JTTM J. Terap. Tek. Mesin*, vol. 4, no. 2, pp. 207-214, 2023.

[2] L. Sule and N. Salam, *Water Energy and Pump*, Makassar: Unhas Press, 2024.

[3] A. Neeraj, P. Anup, S. Anushka, and S. Nitesh, “Design of Pelton turbine and bucket surface using non-uniform rational basis spline and its analysis with computational fluid dynamics,” *J. Inst. Eng*., vol. 16, no. 1, pp. 41-50, 2021.

[4] F. A. Khan, A. Kumar, T. Staubli, A. Abbas, and L. Devinar, “Control of a Pelton turbine with partial jet cutting driven by a cut-in jet deflector,” *Renew. Energy*, vol. 239, article no. 122063, 2024.

[5] H. Zhao, B. Zhu, B. Xu, P. Tang, N. Guo, and W. Zhang, “Investigation on the influence of bucket’s flow patterns on energy conversion characteristics of Pelton turbine,” *Eng. Appl. Comput. Fluid Mech.*, vol. 17, no. 1, article no. 2234435, 2023.

[6] R. Cordebela, W. O. I. Bohorquez, and J. Campos, “Efficiency assessment in a Pelton wheel as a function of the bucket exit angle at several rotational speeds,” *Iran. J. Sci. Technol. Trans. Mech. Eng*., vol. 47, pp. 1571–1584, 2023.

[7] A. T. Manedjeu and P. B. Sob, “Design and modelling of Pelton wheel bucket to improve its efficiency,” *SSRN Electron. J.*, 2024.

[8] O. R. Alomar, H. M. Abd, M. M. M. Salih, and F. A. Ali, “Performance analysis of Pelton turbine under different operating conditions: An experimental study,” *Ain Shams Eng. J.*, vol. 13, no. 4, article no. 101684, 2022.

[9] J. A. S. Del Rio and A. R. Sánchez, “Numerical simulation of different splitter angles of a Pelton bucket to increase the power generated by the Pelton wheel,” *Int. J. Integr. Eng*., vol. 15, no. 7, pp. 1-10, 2023.

[10] M. G. H. Suryaningrat and R. Permatasari, “Optimization of angle deflection on Pelton turbine bucket using CFD,” *J. Phys.: Conf. Ser.*, vol. 2972, no. 1, article no. 012018, 2025

[11] L. Zain, D. S. Fahreza, P. M. Bagus, A. A. Michael, and B. S. Doan, “Experimental study of small hydro turbine propeller performance with a variety of blade angles of attack,” *SINERGI*, vol. 26, no. 3, pp. 273-278, 2022.

[12] A. Chukwuneke, J. L. Chukwuneke, and C. H. Achebe, “Modelling the effect of head and bucket splitter angle on the power output of a Pelton turbine,” *Int. J. Eng. Appl. Sci*., vol. 5, no. 3, pp. 1-8, 2014.

[13] A. R. Sánchez and J. A. S. Del Rio, “Simulation of four different splitter angles of a Pelton bucket,” *Int. J. Mech. Prod. Eng. Res. Dev*., vol. 10, no. 3, pp. 14601-14608, 2020.

[14] P. Rupa and C. L. Mahesh, “Numerical modelling of deflection of the flow at the bucket splitter of Pelton turbine,” *Proc. 12th IOE Grad. Conf*., vol. 12, pp. 985-991, 2022.

[15] R. K. Karre, K. Srinivas, K. Mannan, B. Prashanth, and C. R. Prasad, “A review on hydro power plants and turbines,” *AIP Conf. Proc*., vol. 2418, article no. 030048, 2022.

[16] J. Decaix and C. Münch-Alligné, “Geometry, mesh and numerical scheme influencing the simulation of a Pelton jet with the OpenFOAM toolbox,” *Energies*, vol. 15, no. 19, article no. 7451, 2022.

[17] G. Ibarra, A. Ladino, F. Larrahondo, and S. Rodriguez, “Optimization and reconstruction of Pelton buckets based on statistical techniques, artificial neural networks and CFD modelling,” *Renew. Energy*, vol. 231, article no. 120933, 2024.

[18] T. Kumashiro, H. Fukuhara, and K. Tani, “Unsteady CFD simulation for bucket design optimization of Pelton turbine runner,” *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 49, article no. 022003, 2016.

[19] A. Lipej and B. Popovski, “Numerical aided design of Pelton nozzle jet deflector,” *J. Mech. Energy Eng*., vol. 5, no. 2, pp. 149-156, 2021.

[20] Y. Xiao, Z. Liu, Q. Liang, J. Liu, J. Zhang, Y. Zhu, X. Li, and C. Gu, “The interaction between bucket number and performance of a Pelton turbine,” *Energy*, vol. 263, article no. 129646, 2023.

[21] D. Mafruddin, *Impuls Turbine*. Lampung: Laduny Press, 2020.