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Experimental Study on the Effect of Nozzle Angle and Blade Number on Hydro Turbine Performance

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ABSTRACT

This study investigates the effect of nozzle angle and blade number on the performance of a small-scale hydro turbine. Three nozzle angles, namely 15°, 30°, and 45°, were tested using three runner configurations consisting of 11 blades, 13 blades, and 15 blades. The experiment was conducted using a hydro turbine test rig consisting of a water pump, flow meter, adjustable nozzle assembly, turbine runner, generator, and electrical load system. Water flow was directed through the nozzle toward the runner, and the turbine performance was measured under controlled operating conditions. The tests were carried out at flow rates of 3.5 L/s, 4.5 L/s, and 5.6 L/s, and four electrical load levels of 0 W, 5 W, 10 W, and 15 W. The measured parameters were generator rotational speed, voltage, and current. The results showed that nozzle angle and blade number affected turbine performance. The 30° nozzle angle consistently produced the highest generator speed and voltage output, while the 11-bladed runner demonstrated the best overall performance compared with the 13-bladed and 15-bladed runners. Turbine performance increased with increasing flow rate and decreased with increasing load. The highest performance was obtained at 5.6 L/s using the 30° nozzle angle and 11-bladed runner, indicating the importance of optimizing these design parameters.

Kata Kunci : *Hydro turbine, nozzle angle, Blade number, Flow rate, Small-scale hydro power*

ABSTRAK

Penelitian ini mengkaji pengaruh sudut nozzle dan jumlah bilah terhadap kinerja turbin hidro skala kecil. Tiga sudut nozzle, yaitu 15°, 30°, dan 45°, diuji menggunakan tiga konfigurasi runner yang terdiri atas 11 bilah, 13 bilah, dan 15 bilah. Eksperimen dilakukan menggunakan alat uji turbin hidro yang terdiri atas pompa air, flow meter, rakitan nozzle yang dapat diatur, runner turbin, generator, dan sistem beban listrik. Aliran air diarahkan melalui nozzle menuju runner, kemudian kinerja turbin diukur dalam kondisi operasi yang terkontrol. Pengujian dilakukan pada debit aliran 3,5 L/s, 4,5 L/s, dan 5,6 L/s, serta empat tingkat beban listrik, yaitu 0 W, 5 W, 10 W, dan 15 W. Parameter yang diukur meliputi kecepatan putar generator, tegangan, dan arus. Hasil penelitian menunjukkan bahwa sudut nozzle dan jumlah bilah memengaruhi kinerja turbin. Sudut nozzle 30° secara konsisten menghasilkan kecepatan generator dan tegangan keluaran tertinggi, sedangkan runner 11 bilah menunjukkan kinerja terbaik dibandingkan runner 13 dan 15 bilah. Kinerja turbin meningkat seiring meningkatnya debit aliran dan menurun seiring meningkatnya beban. Kinerja tertinggi diperoleh pada debit 5,6 L/s dengan sudut nozzle 30° dan runner 11 bilah, yang menunjukkan pentingnya optimasi parameter desain tersebut.

Keywords : *Turbin hidro, Sudut bilah, Jumlah bilah, Debit aliran, Konversi energi, Pembangkit hidro skala kecil*

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1. INTRODUCTION

The global demand for sustainable and clean energy sources has significantly increased in recent years, underscoring the need for renewable energy systems such as hydropower. Indonesia, with its vast network of rivers and abundant water resources, is ideally positioned to utilize hydropower as a key solution for decentralized energy generation, especially in remote and rural areas. The country's tropical climate and favorable geographical conditions make it an ideal location for micro-hydropower systems, offering an efficient and environmentally friendly alternative to conventional energy sources [1]-[3]. Micro-hydropower systems have gained popularity due to their low environmental impact, ease of operation, and capacity to provide reliable electricity in off-grid areas [4], [5].

In hydropower systems, the turbine plays a vital role in converting the kinetic energy of flowing water into mechanical energy, which is then transformed into electrical energy through a generator. The performance of a hydro turbine is influenced by various design parameters, including blade geometry, nozzle angle, nozzle diameter, and flow rate. Among these factors, nozzle angle and nozzle diameter are particularly significant because they directly affect the flow characteristics, pressure distribution, and efficiency of the turbine [6]-[8]. Incorrect configuration of nozzle angle or nozzle diameter can increase flow resistance and hydraulic losses, thus reducing overall energy conversion efficiency.

To optimize turbine design, numerous studies have employed Computational Fluid Dynamics (CFD) simulations to analyze fluid flow patterns and performance characteristics. CFD provides a detailed understanding of how variations in nozzle angle and nozzle diameter impact internal flow dynamics, velocity distribution, and pressure behavior within the turbine system [9]-[11]. While CFD models have proven valuable for optimizing turbine design, experimental validation is essential to ensure that the predicted results align with real-world performance, as experimental factors such as mechanical losses and electrical loading may influence actual turbine operation [12]-[15].

This study aims to experimentally investigate the effects of nozzle angle (15°, 30°, and 45°) on the performance of small-scale hydro turbines. By conducting experiments under varying flow conditions, this research seeks to provide practical insights into the optimization of these design parameters to enhance turbine efficiency and performance. The experimental results will also be compared with previous CFD predictions to assess their consistency and reliability. Ultimately, this study seeks to contribute valuable knowledge to the design and development of more efficient small-scale hydro turbine systems.

2. RESEARCH METHOD

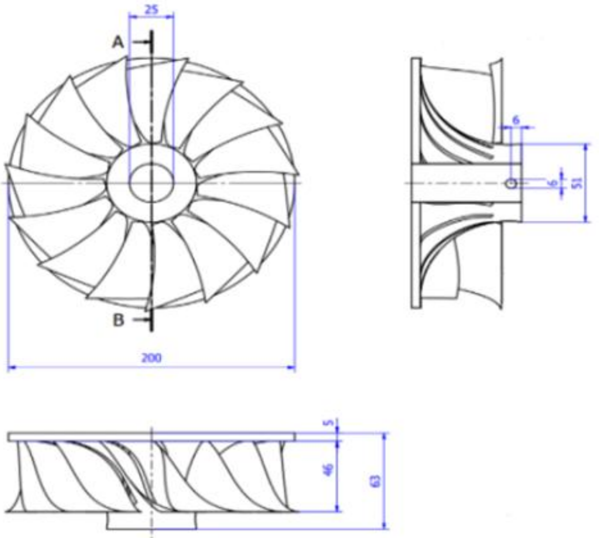

Fig. 1. Turbine Design

By maintaining these design parameters, the experiment aimed to evaluate how changes in nozzle angle (15°, 30°, and 45°) impact the turbine's performance, including rotational speed (rpm), voltage (V), and current (A). The experimental results were compared with CFD simulations to assess the agreement between numerical predictions and actual turbine behavior under various operating conditions. This validation process ensures that the CFD models provide reliable insights into turbine design optimization for improved performance.

The experimental system consisted of a hydro turbine prototype, a controlled water flow supply system, a generator, a tachometer, and a multimeter. The water flow system provided stable operating conditions during the test, while the tachometer measured the generator's rotational speed in revolutions per minute (rpm). The electrical output was measured in terms of voltage and current using the multimeter. The tests were conducted under three different flow rate conditions: 5.6, 4.5, and 3.5 liters per second. The testing procedure began by installing a specific nozzle angle configuration on the turbine runner, followed by supplying water flow at the predetermined flow rate. Once the turbine reached stable operation, the generator's speed, voltage, and current were recorded for each electrical load condition.

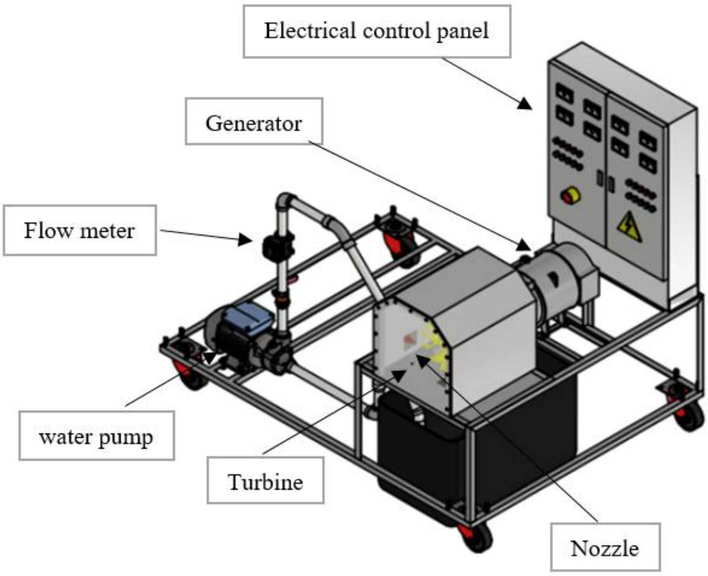

Fig. *2*. Prototype Design

Figure 2 presents the experimental prototype of the small-scale hydro turbine test system used in this study. The main components of the system include a water pump, flow meter, adjustable nozzle assembly, turbine housing, runner, generator, and electrical control panel. The water pump supplies the required flow to the turbine, while the flow meter is used to monitor and regulate the flow rate during testing. The adjustable nozzle assembly directs the water jet toward the turbine runner at a predetermined angle, enabling the effect of nozzle angle variation on turbine performance to be evaluated. The runner, which is enclosed within the turbine housing, converts the kinetic energy of the water flow into mechanical rotational energy. This rotational motion is transmitted through the shaft to the generator, where it is converted into electrical energy. The electrical control panel is used to connect the electrical load and monitor the output parameters during the experiment.

The procedure was repeated for all combinations of nozzle angles (15º, 30º, and 45º) across the three runner configurations (11, 13, and 15 blades) to ensure consistency and comparability of the results. The collected data were then analyzed comparatively to determine the effect of nozzle angle on hydro turbine performance. The experimental results were further compared with previous CFD findings to assess the agreement between numerical predictions and actual turbine behavior under real operating conditions.

3. RESULTS AND DISCUSSION

The experimental results indicate that the performance of the hydro turbine was significantly affected by flow rate, electrical load, nozzle angle, and blade number. In general, higher flow rates resulted in higher generator rotational speed and voltage output, whereas increasing electrical load caused both parameters to decrease. Across all tested operating conditions, the 11-bladed runner consistently exhibited the highest performance, followed by the 13-bladed and 15-bladed runners. This trend suggests that a lower blade number reduced hydraulic resistance within the runner passage and enabled more effective conversion of hydraulic energy into mechanical and electrical output.

Table 1. Experimental results of turbine performance under different flow rates, loads, nozzle angles, and runner blade numbers.

Flow Rate	Load	Nozzle Angle	Generator Speed (rpm)			Voltage (V)			Current (A)		
			11 blades	13 blades	15 blades	11 blades	13 blades	15 blades	11 blades	13 blades	15 blades
3.5	0	15°	714	658	611	16.76	16.07	15.48	0.00	0.00	0.00
3.5	0	30°	760	700	650	17.10	16.40	15.80	0.00	0.00	0.00
3.5	0	45°	737	679	631	16.93	16.24	15.64	0.00	0.00	0.00
3.5	5	15°	395	357	329	8.04	7.64	7.25	0.34	0.33	0.32
3.5	5	30°	420	380	350	8.20	7.80	7.40	0.35	0.34	0.33
3.5	5	45°	407	369	340	8.12	7.72	7.33	0.35	0.34	0.33
3.5	10	15°	216	197	179	7.55	7.15	6.76	0.35	0.34	0.33

Flow Rate	Load	Nozzle Angle	Generator Speed (rpm)			Voltage (V)			Current (A)		
			11 blades	13 blades	15 blades	11 blades	13 blades	15 blades	11 blades	13 blades	15 blades
3.5	10	30°	230	210	190	7.70	7.30	6.90	0.36	0.35	0.34
3.5	10	45°	223	204	184	7.62	7.23	6.83	0.36	0.35	0.34
3.5	15	15°	66	56	52	7.15	6.76	6.37	0.36	0.35	0.34
3.5	15	30°	70	60	55	7.30	6.90	6.50	0.37	0.36	0.35
3.5	15	45°	68	58	53	7.23	6.83	6.44	0.37	0.36	0.35
4.5	0	15°	921	855	799	18.82	18.13	17.44	0.00	0.00	0.00
4.5	0	30°	980	910	850	19.20	18.50	17.80	0.00	0.00	0.00
4.5	0	45°	951	883	825	19.01	18.32	17.62	0.00	0.00	0.00
4.5	5	15°	479	451	423	8.2	8.33	7.94	0.36	0.35	0.34
4.5	5	30°	510	480	450	8.90	8.50	8.10	0.37	0.36	0.35
4.5	5	45°	495	466	437	8.81	8.42	8.02	0.37	0.36	0.35
4.5	10	15°	273	244	226	8.13	7.79	7.45	0.37	0.36	0.35
4.5	10	30°	290	260	240	8.30	7.95	7.60	0.38	0.37	0.36
4.5	10	45°	281	252	233	8.22	7.87	7.52	0.38	0.37	0.36
4.5	15	15°	80	73	66	7.84	7.55	7.06	0.38	0.37	0.36
4.5	15	30°	85	78	70	8.00	7.70	7.20	0.39	0.38	0.37
4.5	15	45°	82	76	68	7.92	7.62	7.13	0.39	0.38	0.37
5.6	0	15°	1128	1053	987	21.27	20.48	19.70	0.00	0.00	0.00
5.6	0	30°	1200	1120	1050	21.70	20.90	20.10	0.00	0.00	0.00
5.6	0	45°	1164	1086	1019	21.48	20.69	19.90	0.00	0.00	0.00
5.6	5	15°	564	512	468	9.27	8.94	8.66	0.38	0.37	0.36
5.6	5	30°	600	545	498	9.46	9.12	8.84	0.39	0.38	0.37
5.6	5	45°	582	529	483	9.37	9.03	8.75	0.39	0.38	0.37
5.6	10	15°	327	291	262	8.71	8.38	8.06	0.39	0.38	0.37
5.6	10	30°	348	310	279	8.89	8.55	8.22	0.40	0.39	0.38
5.6	10	45°	338	301	271	8.80	8.46	8.14	0.40	0.39	0.38
5.6	15	15°	95	83	71	8.43	8.05	7.79	0.40	0.39	0.38
5.6	15	30°	101	88	76	8.60	8.21	7.95	0.41	0.40	0.39
5.6	15	45°	98	85	74	8.51	8.13	7.87	0.41	0.40	0.39

At the flow rate of 3.5 L/s, the influence of nozzle angle on turbine performance was already evident. Under no-load conditions, the 30° nozzle angle produced the highest output for all blade configurations. For the 11-bladed runner, the generator speed reached 760 rpm with a voltage of 17.10 V, whereas the corresponding values at 15° were 714 rpm and 16.76 V, and at 45° were 737 rpm and 16.93 V. A similar trend was observed for the 13-bladed and 15-bladed runners. As the electrical load increased from 0 W to 15 W, the generator speed and voltage decreased substantially for all configurations, while the current increased slightly. For example, at 30° and 3.5 L/s, the speed of the 11-bladed runner decreased from 760 rpm at no load to 420 rpm, 230 rpm, and 70 rpm at loads of 5 W, 10 W, and 15 W, respectively. Over the same loading range, the voltage dropped from 17.10 V to 8.20 V, 7.70 V, and 7.30 V, while the current increased from 0.00 A to 0.35 A, 0.36 A, and 0.37 A. This behavior is consistent with the increased torque demand imposed by higher electrical loading, which reduced shaft rotational speed and terminal voltage.

At the intermediate flow rate of 4.5 L/s, the same overall tendency was maintained, with the 30° nozzle angle again providing the highest performance. Under no-load conditions, the 11-bladed runner achieved 980 rpm and 19.20 V at 30°, compared with 921 rpm and 18.82 V at 15°, and 951 rpm and 19.01 V at 45°. This result indicates that the 30° nozzle angle provided a more favorable jet direction for transferring momentum to the turbine runner. Under loaded conditions, the superiority of the 30° configuration remained consistent. At 5 W, for instance, the 11-bladed runner at 30° produced 510 rpm, 8.90 V, and 0.37 A, which were higher than the corresponding values at 15° and 45°. The same pattern was observed for the 13-bladed and 15-bladed runners, confirming that the influence of nozzle angle was not limited to a single blade configuration.

The highest turbine performance was recorded at the maximum flow rate of 5.6 L/s, where the effect of nozzle angle became more pronounced. Under no-load conditions, the 11-bladed runner with a 30° nozzle angle produced the highest overall output of 1200 rpm and 21.70 V, while the 13-bladed and 15-bladed runners generated 1120 rpm and 20.90 V, and 1050 rpm and 20.10 V, respectively. At the same flow rate, the 15° nozzle angle produced lower outputs of 1128 rpm and 21.27 V for the 11-bladed runner, whereas the 45° configuration produced 1164 rpm and 21.48 V. Under electrical loading, the same ranking was preserved. At 10 W, for example, the 11-

bladed runner at 30° generated 348 rpm, 8.89 V, and 0.40 A, compared with 327 rpm, 8.71 V, and 0.39 A at 15°, and 338 rpm, 8.80 V, and 0.40 A at 45°. These findings show that the 30° angle offered the most effective hydraulic interaction between the water jet and the runner under all tested flow conditions.

A direct comparison among nozzle angles reveals that the 30° nozzle angle consistently provided the best turbine performance. The 45° angle generally ranked second, while the 15° angle produced the lowest output. From a hydraulic perspective, this suggests that the 30° nozzle angle provided a more optimal jet incidence relative to the runner blades, thereby improving momentum transfer and reducing hydraulic loss. In contrast, the 15° angle may have caused insufficient fluid impact on the blade surfaces, while the 45° angle, although more stable than 15°, likely introduced a less effective flow direction for maximizing runner rotation. Therefore, among the tested configurations, the 30° nozzle angle can be considered the most favorable for this turbine geometry.

The effect of blade number was similarly significant throughout the experiment. For every combination of flow rate, load, and nozzle angle, the 11-bladed runner produced the highest generator speed and voltage, followed by the 13-bladed and 15-bladed runners. At 5.6 L/s, 0 W, and 30°, for instance, the output decreased from 1200 rpm for 11 blades to 1120 rpm for 13 blades and 1050 rpm for 15 blades. The same decreasing trend was observed in the voltage output. These results indicate that increasing the number of blades increased the degree of flow obstruction inside the runner, thereby elevating hydraulic losses and reducing the turbine's rotational response. Although a larger blade number may increase the contact area between water and runner, the present results suggest that the negative effect of increased blockage was more dominant than any potential gain in torque under the tested conditions.

In contrast to rotational speed and voltage, the current output showed a slight increase with increasing electrical load. Under no-load conditions, the current remained 0.00 A for all cases because no electrical demand was connected to the generator. Once the load was applied, the current rose gradually and remained relatively stable. For example, at 5.6 L/s, 30°, and 11 blades, the current increased from 0.39 A at 5 W to 0.40 A at 10 W and 0.41 A at 15 W. Comparable trends were also observed for the 13-bladed and 15-bladed runners. This indicates that, despite the reduction in speed and voltage under increasing load, the generator adjusted its current output in response to the external electrical demand.

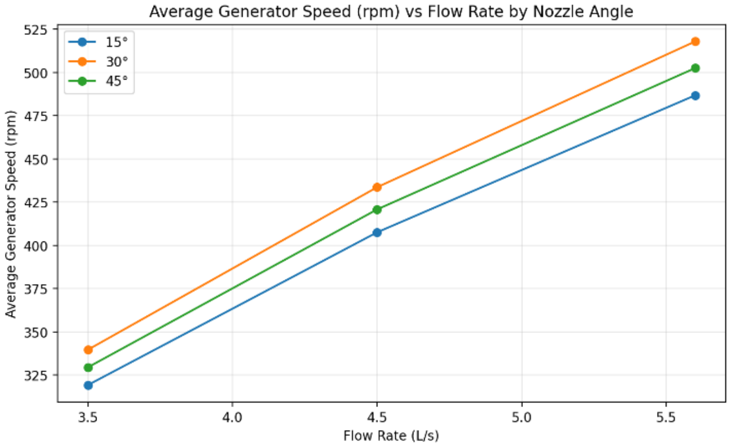

Fig. *3*. Generator Speed vs Flow Rate by Nozzle Angle

Overall, the results demonstrate that the combination of a 30° nozzle angle and an 11-bladed runner produced the most favorable hydro turbine performance across all tested operating conditions. This configuration consistently yielded the highest generator speed and voltage output, particularly at the maximum flow rate of 5.6 L/s. The findings confirm that both nozzle angle and blade number are critical design parameters in the optimization of small-scale hydro turbines. Furthermore, the results show that increasing flow rate improves turbine performance, whereas increasing electrical load reduces generator speed and voltage while slightly increasing current. These observations provide practical insight for the design and optimization of hydro turbine systems intended for small-scale renewable energy applications.

4. CONCLUSION

This study confirms that nozzle angle and blade number are important parameters affecting the performance of a small-scale hydro turbine. Among the tested nozzle angles, the 30° configuration consistently produced the highest generator speed and voltage output under all flow rate and load conditions, indicating that it provided the most favorable flow direction for energy transfer to the runner. In contrast, the 45° nozzle angle showed slightly lower performance, while the 15° nozzle angle resulted in the lowest overall output. The results also demonstrate that the 11-bladed runner consistently outperformed the 13-bladed and 15-bladed runners, suggesting that a lower blade number reduced flow obstruction and hydraulic losses within the turbine.

In addition, turbine performance improved as the flow rate increased and decreased as the electrical load increased. Higher flow rates provided greater hydraulic energy, leading to higher rotational speed and voltage output, whereas higher electrical loads increased generator torque demand and reduced turbine speed and voltage. Meanwhile, the current output increased slightly with increasing load. Overall, the combination of a 30° nozzle angle and an 11-bladed runner was identified as the most favorable configuration for achieving better hydro turbine performance, highlighting the importance of optimizing these design parameters in small-scale hydropower applications.

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