Experimental Study of Gravitational Water Vortex Turbine at Flow Angle 70 Deg Inclined Blade

Imanuel Sinuraya [1], Tulus Burhanuddin Sitorus [1], Idham Kamil [2]

[1] Department of Mechanical Engineering, Universitas Sumatera Utara, North Sumatra, Indonesia
[2] Department of Mechanical Engineering, Politeknik Negeri Medan, North Sumatra, Indonesia

Imanuelsinuraya@students.usu.ac.id
tulus.burhanuddin@usu.ac.id
idhamk@gmail.com

Abstract

The study highlights the impact of increasing population growth, geographic change, and rapid development on global energy demand. The high reliance on non-renewable resources, such as oil and coal, poses significant sustainability challenges, given depleting reserves and increasing environmental impact. Renewable energy, which is renewable and naturally maintained, plays a crucial role in addressing the global energy crisis and facing future climate challenges. In-donesia, with the potential for renewable energy resources such as solar, wind, water, biomass, geothermal, and tidal energy reaching 3,692 gigawatts (GW), is the main focus of this research. Gravity Water Vortex Energy Gener- ation (GWVP) technology, which offers an environmentally friendly solution for generating renewable energy through water flow in cylindrical containers, was researched to evaluate how vessel geometry and turbine design affect GWVP performance. The general purpose of this study is to conduct performance tests of vortex turbines. The re- search aims to improve the performance of vortex turbines by using experimental methods. The experimental approach will involve the development of test equipment equipped with a data acquisition system. Through an experimental ap- proach, this study shows that increasing the number of turbine blades in GWVP can significantly improve power and efficiency, especially in the face of variations in water flow velocity. These findings provide new insights into the de- velopment of GWVP technology as a more effective and sustainable renewable energy source.

Keywords: micro-hydro, performance, vortex turbine

1 Introduction

The continuous growth in population, regional development, and ongoing construction annually escalates global energy demand alongside technological and industrial progress. Historically, this demand has heavily relied on non- renewable resources like oil and coal, whose sustainability cannot ensure long-term needs due to depleting reserves formed over millions of years. Transitioning to renewable energy is critical for sustainability and to address future climate challenges. With rising global energy consumption, there is an urgent need for further research and development in renewable energy to combat the worsening energy crisis. Renewable energy sources, which replenish naturally and sustainably, offer a viable alternative. Indonesia possesses diverse renewable energy sources capable of replacing fossil fuels. Research primarily focuses on harnessing water flow for micro-hydro power plants to generate electricity, although hydroelectric technology remains relatively basic compared to other renewable options.

V. Mardiansyah and B. A. Prasetyo (eds.), *Proceedings of the Widyatama International Conference on Engineering 2024 (WICOENG 2024)*, Advances in Engineering Research 252,
https://doi.org/10.2991/978-94-6463-618-5_18

Research on renewable energy is increasingly in demand because it aligns with the UN's SDG-7 goal of providing everyone with affordable, clean, and sustainable energy. Adopting renewable energy is crucial in advancing environmentally friendly and sustainable energy, reducing greenhouse gas emissions, and reducing climate change's impact (Trinh & Chung, 2023). Indonesia has a variety of renewable energy sources that can replace fossil fuels. Currently, research mainly focuses on using water streams for micro-hydro plants to generate electricity, although hydroelectric technology is still relatively basic compared to other renewable options.

Approximately20% of the world's electricity needs are met by hydroelectric power plants (HEPP). In Indonesia, there are several significant HEPPs, such as PLTA Singkarak (West Sumatra), PLTA Gajah Mungkur (Central Java), PLTA Karangkates (East Java), PLTA Riam Kanan (South Kalimantan), and PLTA Larona (South Sulawesi) (Apriliyanti & Rizki, 2023). According to an analysis by the International Renewable Energy Agency (IRENA), the potential re- newable energy sources in Indonesia are estimated to reach 3,692 gigawatts (GW), including solar, wind, hydro, biomass, geothermal, ocean currents, and others (Ahdiat, 2022). Specifically, Indonesia has a solar energy potential of approximately 2,898 GW, an offshore wind energy potential of around 589 GW, and a hydropower potential of 94.6 GW. Additionally, Indonesia has the world's most considerable geothermal potential, reaching 23.4 GW.

Research indicates that Gravitational Vortex Air Power Plants (GWVP) may be more advantageous or unique than other energy methods, especially regarding efficiency and environmental impact. A study by (Saleem et al., 2020) reveals that GWVP can enhance efficiency by increasing vortex height and blade shaft rotation, even at low flow rates, making it an appealing alternative to conventional technologies that typically require high flow. Research shows that vortex turbines using cylindrical basins and inclined blades can achieve adequate peak power and efficiency, indi- cating GWVP's ability to harness suboptimal water flow (Kamil et al., 2023). Additionally, (Nishi et al., 2019)used Par- ticle Image Velocimetry (PIV) and simulations to analyze axial flow, revealing how slipstream and vorticity can be effectively managed in GWVP, reducing the impact on water quality. (Ambarita et al., 2023) Demonstrated that varying the number of blades on vortex turbines can enhance torque, power, and efficiency, highlighting the optimi- zation potential of GWVP. Although IRENA's reports do not specifically address GWVP, Indonesia's significant renewable energy potential suggests that this technology could leverage neglected water resources. Overall, GWVP of- fers notable benefits in terms of energy efficiency and environmental impact, making it a compelling solution com- pared to other energy generation methods. The gap in some of these studies lies in the inaccuracy and significant variation of results from previous studies regarding the design and materials of vortex turbine impellers and their impact on efficiency and power generated. Previous research has shown that variations in the impeller's size, shape, and material can affect turbine performance differently, with some studies reporting a decrease in efficiency after material modification. In addition, there is a need for a more in-depth analysis of how design changes, such as the number of blades and tilt angles, affect the performance of vortex turbines under varying conditions. This study aims to further explore the influence of impeller design and material on the efficiency and power of vortex turbines with an experi- mental approach.

Technologies such as Gravitational Water Vortex Power Plants (GWVP) offer environmentally friendly solutions to harness low-flow water with minimal emission impact. They can also improve water quality (Rahman et al., 2017). The uneven cost of electricity usage is a crucial reason why renewable energy is a vital solution for Indonesia, particularly in electricity generation. By mid-2020, the share of renewable energy in Indonesia's electricity generation was still less than 15% (IESR Institute for Essential Services Reform, 2021). Gravitational Water Vortex Power Plant (GWVP) is a potential solution to generate renewable energy using water flow in a cylindrical container. This study evaluates how the container geometry and turbine design affect GWVP performance.

Although previous efforts have been made to improve GWVP design, a deeper understanding of the interaction between water flow and the turbine within the conical container is still needed. Therefore, an experimental approach is used in this study to investigate the impact of turbine power enhancement on the efficiency and performance of GWVP. The results of this study will provide new insights into the development of GWVP technology as a more effective and sustainable renewable energy source (Edirisinghe et al., 2022). The vortex turbine is a micro hydro turbine that uses water vortices to drive its blades.

2 Materials and Methods

The research was conducted in the Fluid Mechanics Laboratory, Department of Mechanical Engineering, Universitas Sumatera Utara, using various equipment and materials. The equipment used in this study includes:

1. Vortex Turbine Impeller Design with 9, 7, and 5 blades,
2. Basin and Intake Tunnel,
3. Gate valve,
4. Centrifugal pump,
5. Electric generator,
6. Digital scales,
7. Portable flowmeter,
8. Digital tachometer, and
9. Digital KWH meter.

This study has an experimental layout designed to test the power generation system with the GWVT system, as shown in Figures 1 and 2.

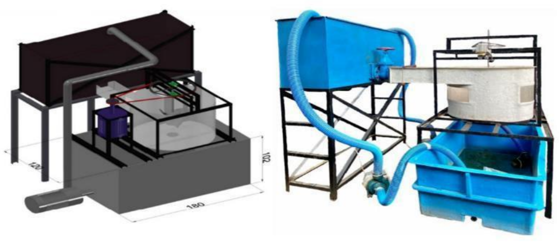

Figure 1. Experimental Design and Layout (Kamil et al., 2023)

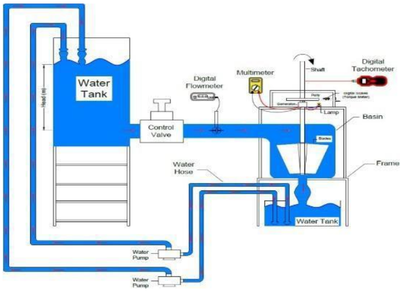

Figure 2. Experimental scheme (Kamil et al., 2023)

The experimental procedure includes installing a nine-blade vortex turbine, preparing a turbine shaft, assembling these components in a cylindrical basin, and ensuring stable water conditions for testing. Following setup, adjustments are made to achieve water speeds of 2 m/s, 2.2 m/s, and 2.5 m/s by adjusting valves. Data collection involves measuring shaft rotation speed, varying the height by 0.6 meters, and analyzing gravitational forces during vortex rotation. Torque and power output are also recorded, with tests repeated for five and seven-blade configurations, followed by compiling results into testing tables. The magnitude of torque and shaft rotation influence the power output of turbines, so data is necessary for calculations and analysis. Abdul Samad Saleem researched vortex gravity water turbines in this experiment, and this calculation formula was used to process the data (Saleem et al., 2020). Water power is the power generated by water per unit area. Essentially, water power is the movement of water per unit time and can be defined as follows:

$$P_{water} = \rho \cdot g \cdot v \cdot H \qquad (1)$$

Turbine Power Turbine power is generated by the turbine rotor after extracting energy from the water flow.

$$P_{turbine} = \tau \cdot \omega \qquad (2)$$

Torque: The rotational force generated by the turbine shaft or the turbine's ability to perform work is known as torque. The following equation describes the torque formula:

$$\tau = F \cdot r_p \qquad (3)$$

Angular Velocity/Turbine Rotation Speed Angular velocity is another term for rotational speed. The formula for angular velocity can be found in the following equation:

$$\omega = \frac{\Delta\theta\ (2\cdot\pi\cdot r)}{\Delta t} \qquad (4)$$

Turbine Efficiency Turbine efficiency is the turbine's ability to generate mechanical energy from potential energy or convert potential energy contained in water into mechanical energy to drive a generator

$$\eta = \eta_T = \frac{P_{water}}{P_{turbine}} x\ 100\% \qquad (5)$$

3 Result and Discussions

The parameters analyzed include speed, blade rotation, torque, and power generated. The study also investigated the effect of blade number and valve opening on these performance parameters. Various blade configurations were tested under three different valve openings, maintaining constant flow rates of 0.0225 m^3 /s, 0.0154 m^3 /s, and 0.0140 m^3 /s with a whole water level of 1 m inside the reservoir. The torsion testing involved various pulley loads that affected the blade rotation until it stopped.

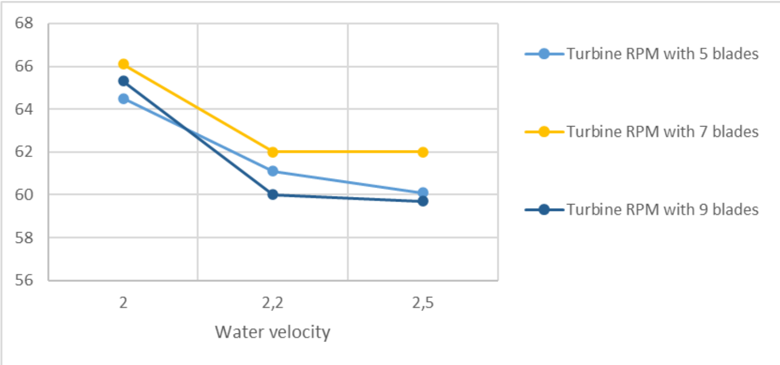

Figure 3. Rotation (RPM) vs Water Height(m)

Figure 3 illustrates the performance of turbines with different numbers of blades 5, 7, and 9 blades against changes in water velocity. At a water speed of 2 m/s, the turbine with seven blades shows the highest performance with an RPM of about 66, while the turbines with five blades and nine blades have RPMs of about 64 and 62, respectively. However, as the water speed increases up to 2.5 m/s, all turbines experience a decrease in RPM. The turbine with seven blades experienced the most significant decrease at a water speed of 2.2 m/s but stabilized at 62 RPM when the speed reached 2.5 m/s. In contrast, turbines with 5 and 9 blades showed a more gradual and consistent decrease, ending with RPMs of around 59 and 58 at the highest water speed. These results show that seven-blade turbines are more efficient at low water velocities. However, their performance decreases more drastically than turbines with 5 and 9 blades as the water velocity increases. Despite having the lowest overall RPM, the turbine with nine blades showed the most stable performance degradation among these three types of turbines.

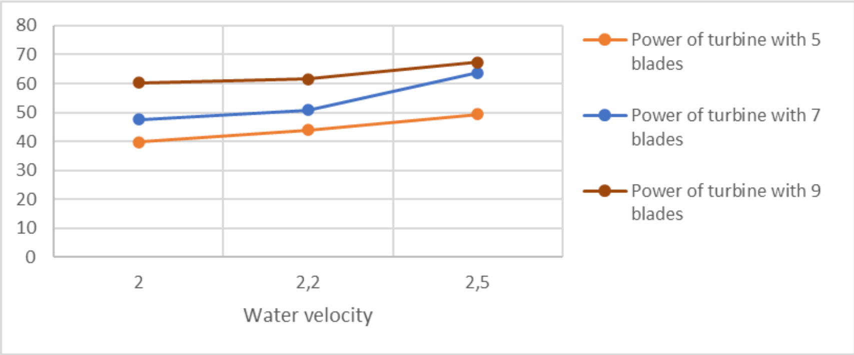

Figure 4. Turbine Power ($P_{Trurbine}$) vs Water Height (m)

Figure 4 illustrates the relationship between water velocity and the power generated by turbines with varying numbers of blades, namely 5, 7, and 9 blades. At a water speed of 2 m/s, the turbine with nine blades produces the highest power, about 70 watts, followed by the turbine with five blades, with about 60 watts, and the turbine with seven blades produces the lowest power, about 45 watts. As the water speed increased to 2.5 m/s, all turbines showed increased power generated. The turbine with nine blades performed the best, with the power steadily increasing to about 75 watts. Meanwhile, the turbine with seven blades experienced a significant increase in power to reach about 60 watts at the highest water speed, almost matching the power generated by the turbine with five blades, which reached about

65 watts. Overall, the turbine with nine blades performed best in generating power over a wide range of water velocities, followed by the turbine with five blades was also entirely consistent in generating power. Although initially having the lowest power at low water speeds, the turbine with seven blades showed significant improvement with increasing water speed. These results show that the number of blades on a turbine affects the power generated, with turbines with more blades tending to be more efficient over a wide range of water speeds.

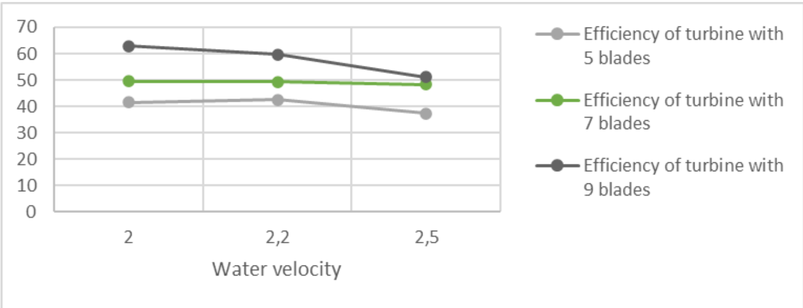

Figure 5. Efficiency vs Water Height (m)

Figure 5 shows the relationship between water velocity and the efficiency of turbines with different numbers of blades, namely 5, 7, and 9 blades. At a water speed of 2 m/s, the turbine with nine blades has the highest efficiency, about 60, followed by the turbine with five blades, which has an efficiency of about 50. In contrast, the turbine with seven blades has the lowest efficiency, about 45. As the water speed increases up to 2.5 m/s, the efficiency of the turbines with 9 and 5 blades tends to decrease. The turbine with nine blades shows a significant drop in efficiency, from about 60 at 2 m/s to about 50 at 2.5 m/s. The turbine with five blades also showed a consistent decrease in efficiency, from about 50 to about 40.

In contrast, the turbine with seven blades showed a relatively stable efficiency across the entire range of water velocities tested, remaining around 45 to 50 without significant change. This indicates that the turbine with seven blades has better efficiency and stability, albeit to a lesser extent than the other turbines. These results indicate that while the turbine with nine blades has the highest efficiency at lower water velocities, its efficiency decreases as the water velocity increases. The turbine with five blades also experienced a similar decrease in efficiency but with lower initial values. Despite having the lowest initial efficiency, the turbine with seven blades showed the most stable per- formance across a wide range of water velocities.

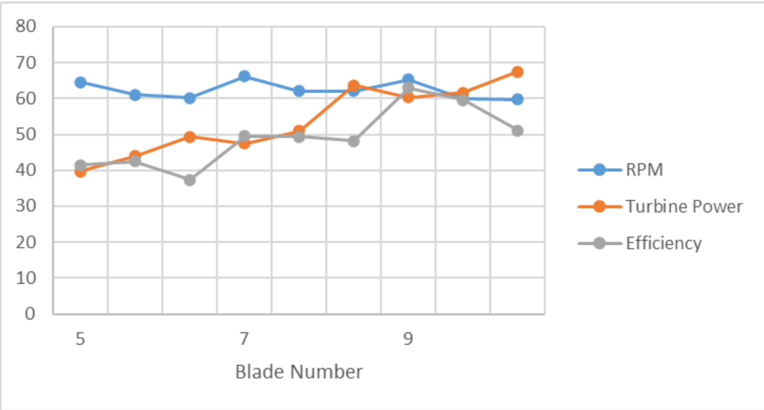

Figure 6. Blade Number Vs. RPM, Turbine Power, and Efficiency

Figure 6 illustrates how RPM, Turbine Power, and Efficiency vary with blade count in vortex turbines. RPM remains stable at 60-70 despite more blades, indicating stable flow. Turbine power rises with more blades, improving energy capture from vortex flow. Efficiency also increases, showing enhanced energy conversion despite fluctuations from factors like blade design and flow velocity. Optimal blade count maximizes energy capture while minimizing losses from friction and turbulence in vortex turbines.

4 Conclusion

Turbines with seven blades have the best performance at low water velocities but experience a more drastic drop in performance with increasing water velocity than turbines with 5 and 9 blades. Turbines with nine blades had the highest efficiency at low water speeds and produced the best power over a broader range of speeds but experienced a significant drop in efficiency at high speeds. The turbine with five blades showed a consistent decrease in power and efficiency with increasing water speed but remained in the middle position com- pared to the turbines with 7 and 9 blades. The 7-bladed turbine had the best efficiency stability across a wide range of water velocities despite having a lower initial effi- ciency than the other turbines. The vortex turbine design maintains a stable rotational speed despite varying water velocities. The turbine with more blades, i.e. nine blades in particular, increases the power output at higher water velocities, enhancing the capture of energy from the flow. Efficiency increased in turbines with more blades 7 and 9, indicating better water flow conversion into mechanical energy. This study underscores the importance of optimizing the number of blades on a vortex turbine to maximize power and efficiency under different water flow conditions, emphasiz- ing the role of blade design and configuration.

Acknowledgments

The author would like to thank the DRTPM of Higher Education, Ministry of Ed- ucation and Culture of the Republic of Indonesia, for research funding assistance with contract number 95/UN5.4.10.S/PPM/KP-DRTPM/2024, and Research Insti- tute of Universitas Sumatera Utara (Lembaga Penelitian USU).

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