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Effect of blade cap variation on overshot pinwheel performance

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Abstract: Waterwheels are a medium for producing electrical energy in micro-hydro power plants sourced from waterways that have speed and height. The energy that can be obtained from a waterwheel should depend on the variation of the blades and the placement of the wheel but, the losses caused by wasted water are large. Therefore, this study makes an overshot waterwheel by using blade variations at the top to reduce losses and see the effect of these variations. This study uses 1 wheel with 4 variables: waterwheel without lid (T), waterwheel top blade closed 1/3 (T 1/3), waterwheel top blade closed 1/2 (1/2), and waterwheel top blade closed 2/3 (T2/3). This wheel uses mahogany wood and the blade cap uses acrylic with a thickness of 3mm. The waterwheel was tested using pipes with sizes and flow rates of 1 m^3/hour, 2 m^3/hour, 3 m^3/hour, 4 m^3/hour, 5 m^3/hour, 6 m^3/hour. The efficiency of the capless waterwheel is greater than the closed-blade waterwheel variation. In this study, the 1/3 closed blade waterwheel (T 1/3) is more efficient because the impact losses of the wheel (T 1/3) are lower at 720.13 when compared to the wheel without a lid (T) 1251.90 and the efficiency of the 1/3 closed blade waterwheel (T 1/3) is much higher at 64.38% when compared to the 2/3 closed blade waterwheel (T2/3) at 33.53%. Therefore, the results of this study show that the 1/3 (T 1/3) wheel is more recommended because it has a high enough efficiency and low impact losses.

Keywords: Waterwheel; losses; efficiency; micro-hydro

1. INTRODUCTION

Electrical energy is one of the essential basic needs in the world today, with the majority of almost all human activities involving electrical energy [1] Thus, the consumption of electrical energy, which initially increased by 1.8% from 2011 to 2012, rose to 4% from 2017 to 2018 [2]. This is due to the increase in population, which leads to higher energy consumption. Meanwhile, the availability of non-renewable natural resources is limited, and resources from fossil fuels are becoming scarce or their use is already restricted [3]. Humans have used various sources of power, including gasoline, diesel, steam turbines, hydro turbines, and electricity [4]. Due to the limitations of fossil energy, renewable energy is being considered as an alternative resource for electricity generation. Various studies are currently being conducted using hydropower to generate electrical energy. Hydropower is often used as a driving force. The process of converting water energy into electricity also motivates many countries to start assessing their energy resources [5].

Water has both kinetic and potential energy, making it a cheap and simple source of energy [6]. Water energy is one of the resources that can be developed in Indonesia, especially in mountainous areas and irrigation channels that have significant hydropower potential [7]. With current technological advancements, micro-hydropower plants use water resources as an alternative energy source, and water wheels have become one of the mediums to generate electricity through hydropower [8]. There are several types of water wheels: overshot, breastshot, and undershot [9]. Water flow from rivers, irrigation channels, or waterfalls in rural or remote areas that are off the electricity grid can be utilized as Micro-Hydropower Plants (MHPP) [10]. Water wheels are one of the oldest hydraulic devices known to humans and have been used for many years. Due to a lack of understanding of how potential and kinetic energy work, water wheels are therefore inefficient [11]. Water wheels are one of the oldest hydraulic devices known to humans and have been used for many years. Due to a lack of understanding of how potential and kinetic energy work, water wheels are therefore inefficient [12] .

By using a water wheel, potential energy in the form of torque on the wheel can be converted into mechanical energy [13]. In addition to being a method for distributing water for agriculture, waterwheels can also be used as power generators [14], water wheels have high torque and a very simple design; however, improving the performance of micro hydro power plants (PLTA) using water wheels is necessary to enhance the efficiency of hydropower [15].

Water wheels generate power due to the weight of water entering the buckets. To achieve better efficiency of water wheels, as much water as possible should enter the wheel while minimizing what is discharged. Despite numerous studies on water wheels, such as research on the effects of enclosed wheels on efficiency and losses [16], The variation in blade thickness affects the performance of flat-blade water wheels [17], Optimizing the performance of overshot water wheels at high rotational speeds for hydroelectric power generation applications [19]. Therefore, this research aims to reduce losses in water wheels. However, there has been no focused study on reducing losses in water wheels using blades with closed upper parts. Hence, the objective of this study is to investigate the effect of variations in blade covers and to reduce losses in water wheels using blades with closed upper parts.

2. METHOD

The methodology used in this study is experimental, involving testing by measuring the efficiency and losses of the water wheel with various covers on the upper part of the blades [20]–[22]. The water wheels used are uncovered water wheels and water wheels with closed upper parts on the blades.

Research design

In this study, an acrylic cover is used on the upper part of the blades of an overshot water wheel with variations: 2/3 cover (T 2/3), 1/2 cover (T 1/2), 1/3 cover, and uncovered (Without Cover). This is done to maintain the flow of water inside the buckets and is compared with uncovered blades (Without Cover) in the design of an overshot water wheel as shown in Figure 1.

(a) (b) (c) (d)

Figure 1. (a) Water wheel without cover, (b) Water wheel with 1/3 cover,(c) Water wheel with 1/2 cover, (d) Water wheel with 2/3 cover.

Tools and materials

In the data collection process, tools are needed to measure variables on the waterwheel, and the measuring instruments used are shown in Table 1.

Table 1. Measuring instruments

Measuring Instruments	Function	Type
Tachometer	Measuring the rotation of the waterwheel	KW06-563
Torque meter	Measuring the torque rotation of the waterwheel	Lutron TQ-8000
Flow Velocity meter	Measuring the water velocity	Flowatch FL-03
Rotameter	Measuring the water flow rate	LZS 65 Z

Data collection for the study of water wheels with uncovered and covered blade variables uses a single water wheel. This wheel has a diameter of 450 mm and a width of 300 mm, made from mahogany wood with acrylic covers on the blades, each 3 mm thick. Figure 2 shows the comprehensive design of an overshot waterwheel.

Figure 2. Overall water wheel design

- Research location: The research work, from device fabrication to data collection, is conducted at the Laboratory of Mechanical Engineering, Faculty of Industry and Informatics, Universitas Muhammadiyah Prof. DR. Hamka.
- Research procedure: Data collection is the next stage of the research process and is essential to obtain the information needed to answer the problem formulation. Proper and accurate data collection is necessary for the research findings to be representative and reliable.
- Data collection process: The data processing for this research is conducted at the Laboratory of Mechanical Engineering, Faculty of Industry and Informatics, Universitas Muhammadiyah Prof. DR. Hamka, DKI Jakarta. The study aims to compare four variables: T 2/3 (2/3 cover), T 1/2 (1/2 cover), T 1/3 (1/3 cover), and T (uncovered) water wheels. These variations are designed to reduce losses and investigate the effects of blade cover variations on water wheel performance.

In the data collection experiment, 6 flow rate variations were used: 1, 2, 3, 4, 5, and 6 m3/hour. Water is directed from the top of the water storage tank downward through a pipe, passes through a rotameter, and the flow is collected with a trough. The water flows from the trough, rotates the water wheel, and the water falling from the wheel is pumped back up to the top of the water storage tank as shown in Figure 3.

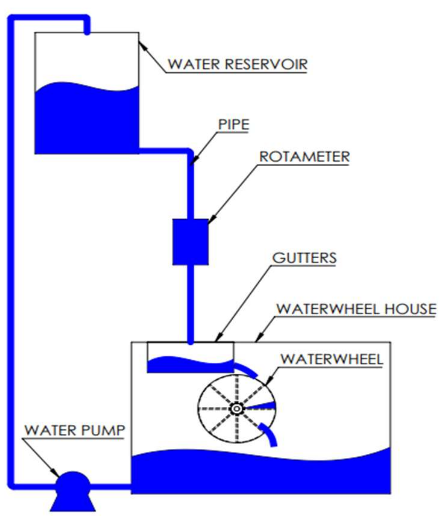

Figure 3. Water wheel testing schematic

Power is generated by the difference in water flow entering the water wheel. To calculate the water power, we use equation (1) as follows [23].

$$P_{in} = \rho \times Q \times g \times H \quad (1)$$

Where:
ρ = Density of water (1000 kg/m^3)
H = Water head (0,73 m)
g = Gravity (9,81 m/s)

The power of the water wheel is calculated using equation (2) [24].

$$P_{out} = T\ x\ \omega \quad (2)$$

$$P_{out} = T\ x \frac{2\pi n}{60} \quad (3)$$

Where:
T = Torque (Nm)
n = Rotation of the water wheel (Rpm)

Efficiency is obtained by comparing the power generated by the water wheel to the water power to determine the achieved wheel efficiency. Equation (4) is used in the calculation of wheel efficiency [2][25]:

$$\eta = \frac{P_O}{P_i}\ x\ 100 \quad (4)$$

Water force (F_a) moving the water wheel blades, generated by the moving water mass ($\dot{m}$), produces a tangential force (F_t) on a wheel that is perpendicular to its axis, thus creating wheel force (F_e) [26].

$$\dot{m} = \rho \times A \times v \quad (5)$$

$$F_a = \dot{m} \times (V_2 - V_1) \quad (6)$$

$$F_t = \frac{F_a}{\cos\theta} \quad (7)$$

Impact losses (L_{imp}) can occur in the water wheel and the channel. Impact losses can be calculated using equation (8) as follows [18]:

$$L_{imp} = \xi\ Y\ Q \frac{w^2}{2_g} \quad (8)$$

where:
ξ = Impact coefficient
Y = Specify gravity of water (N/m^3)
W = Relative velocity (m/s)
g = Gravity (9,81 m/s)

To obtain the relative velocity, it can be determined using equation (9) [18]:

$$W = V - u \quad (9)$$

Where:
V = Water flow velocity (m/s)
U = Tangential velocity (m/s)

Volumetric losses occur at the point where water enters the water wheel, with some of the water flow lost as it enters the wheel. Volume losses can be expressed using equation (10) as follows [18]:

$$L_{Qu} = Y\ Q_u\,(H_u - H_d) \quad (10)$$

Where:
Y = specify gravity of water (N/m^3)
Q_u = blade volumetric losses (m^3/s)
H_u = Surface water flow height (m)
H_d = Waterlogging height (m)

3. RESULTS AND DISCUSSION

After the data collection is complete, it will be continued by processing the data. The results of the overshot waterwheel research data resulted from the power of this overshot waterwheel. The speed of water flow can be measured using different water discharges, then the rpm of the mill to measure the rotation speed of the mill.

Data collection involves using flow rates of 1 m^3/hour, 2 m^3/hour, 3 m^3/hour, 4 m^3/hour, 5 m^3/hour, and 6 m^3/hour pumped through, with variables for the waterwheel (T), waterwheel (T 2/3), waterwheel (T 1/2), and waterwheel (T 1/3). After completing data collection, proceed with creating data tables as shown in Table 2, Table 3, Table 4, and Table 5.

Table 2 shows the calculation results from the data processor on the open waterwheel (T). In this table, the rotation speed of the mill (n) and the power out (P_{out}) increase with the increase of the flow of water discharge (Q), but the efficiency (η) tends to decrease as the water discharge increases.

Table 2. Waterwheel without

Q (m^3/hours)	n (rpm)	P_{in} (W)	P_{out} (W)	η (%)
1	40,31	1,99	1,69	84,87%
2	59,66	3,98	2,50	62,81%
3	78,58	5,97	3,29	55,15%
4	93,73	7,96	3,93	49,34%
5	113,24	9,95	4,74	47,69%
6	124,61	11,94	5,22	43,73%

Table 3 shows the calculation results from the data processor on the waterwheel 1/3 (T 1/3). It is evident that as the water flow rate (Q) increases, the rotational speed of the waterwheel (n) and the power output (P_{out}) also rise. However, efficiency (η) tends to decrease with the increase in water flow rate, with efficiency fluctuations being more pronounced compared to the waterwheel without a cover.

Table 3. 1/3 waterwheel

Q (m^3/hours)	n (rpm)	P_{in} (W)	P_{out} (W)	η (%)
1	30,57	1,99	1,28	37,64%
2	40,04	3,98	1,68	37,64%
3	55,99	5,97	2,35	37,64%
4	78,17	7,96	3,27	37,64%
5	99,68	9,95	4,18	37,64%
6	107,26	11,94	4,49	37,64%

Table 4 shows the calculation results from the data processor on the waterwheel 1/2 (T 1/2). Displaying the performance of the 1/2 waterwheel with various flow rates (Q) in m^3/hour. It is observed that the rotational speed (n) and output power (P_{out}) increase with higher flow rates, but efficiency (η) decreases. This drop in efficiency might be due to the imbalance in rotation at higher flow rates.

Table 4. Water wheel 1/*2*

Q (m^3/hours)	n (rpm)	P_{in} (W)	P_{out} (W)	η (%)
1	22,22	1,99	0,93	46,79%
2	26,95	3,98	1,13	28,37%
3	44,96	5,97	1,88	31,56%
4	51,44	7,96	2,15	27,08%
5	53,45	9,95	2,24	22,51%
6	54,43	11,94	2,28	19,10%

Table 5 shows the calculation results from the data processor on the waterwheel 2/3 (T 2/3). Illustrates the performance of the 2/3 waterwheel with different flow rates (Q) in m^3/hour. The rotational speed (n) and output power (P_{out}) rise with increasing flow rates, but the efficiency (η) decreases.

Table 5. 2/3 waterwheel

Q	n	P_{in}	P_{out}	η

(m^3/hours)	(rpm)	(W)	(W)	(%)
1	15,92	1,99	0,67	33,53%
2	20,18	3,98	0,85	21,25%
3	32,72	5,97	1,37	22,97%
4	38,68	7,96	1,62	20,36%
5	44,92	9,95	1,88	18,92%
6	46,04	11,94	1,93	16,16%

The amount of water flowing on the wheel affects the performance of the wheel which is set to a torque of 0.4 Nm. In the table above are the waterwheel variables used. From the water wheel (T), the wheel (T 1/3), the wheel (T1/2), and the wheel (T 2/3) increases as the water flow increases. However, in the waterwheel without a lid (NT) the resulting rotation is greater than the pinwheel (T 2/3). The flow of water entering the blade of the pinwheel directly falls to the bottom of the pinwheel house resulting in the pinwheel rotating immediately, while for waterwheels with closed blades, 2/3 can slow down the rotation of the pinwheel because at the top of the pinwheel blade is closed so that the flow of water entering the pinwheel blade is accommodated first before falling to the bottom of the pinwheel house which results in losses in the closed blade pinwheel lower than on the waterwheel without a lid [27]. Even in contrast to previous research [28]–[31].

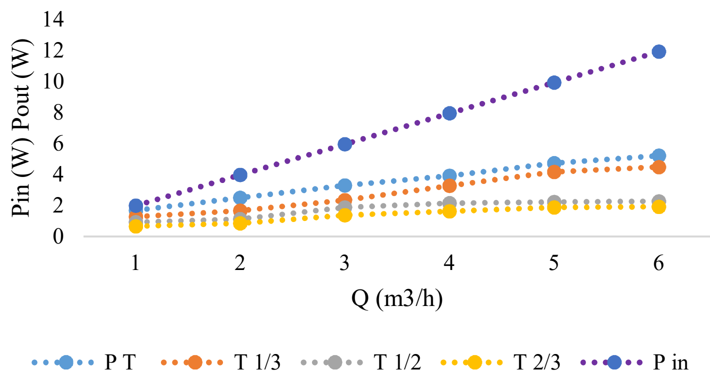

Figure 4. Graph of mill power (P_{in}), water power (P_{out}), and water discharge (Q)

Figure 4 includes the power and water flow. It can be seen that the increase in water flow results in increased water power and mill power. Because the rate of water flow increases, it is certain that the kinetic energy increases to move the blade. This is also influenced by the variation of the lid on the pinwheel blade, the more the upper blade is closed, the power generated will decrease. Although the torque has been set to 0.4 Nm, the pinwheel power (T) is greater than the closed pinwheel power (T 1/3), (T1/2), (T 2/3).

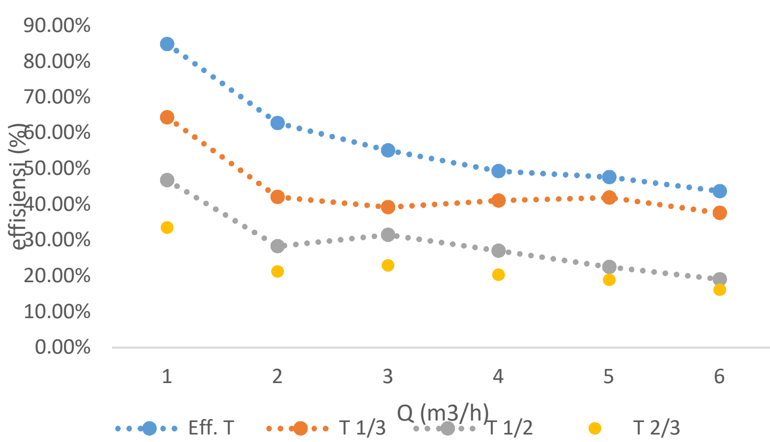

Figure 5. Efficiency Graph

Figure 5 displays the efficiency of the waterwheel without a lid (T), closed pinwheel (T 1/3), (T ½), and (T 2/3) the discharge used is 1 m3/h to 6 m3/h and produces the maximum efficiency of the variable pinwheel without a lid (T), (T 1/3), (T 1/2), and (T 2/3) of 84.87%, 64.38%, 46.79%, 33.53%. The figure above also shows that the effect of variation of the pinwheel blade cap causes the efficiency to decrease along with the increase in discharge, which is where the rotation speed of the pinwheel is not proportional to the increase in water discharge. If you look at previous research, waterwheels with closed blade variations are more efficient [32], [33].

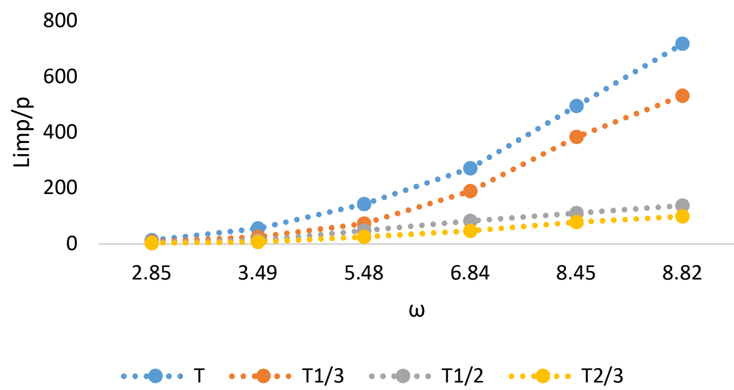

Figure 6. Impact loss velocity (Limp) at angular velocity (ω)

Figure 6 shows that the impact loss graph increases with increasing angular velocity. But for the impact loss on the waterwheel on the closed blade is lower than the waterwheel without closed blades. This is because the more the blade is closed, the more losses generated are low and in a closed blade waterwheel, the flow of water entering the blade of the pinwheel sprays splashes onto the blade cap which causes low loss and provides thrust to the pinwheel.

In Figure 4, the graphs show the waterwheel power (Pin), water power (Pout), and water flow rate (Q). In Figure 5, the graph shows efficiency, and in Figure 6, the graph shows the impact of loss speed (Limp) on angular velocity (ω). The comparison of the highest losses is as follows: open waterwheel at 1251.90, waterwheel with 1/3 covered blades at 720.13, waterwheel with 1/2 covered blades at 380.26, and waterwheel with 2/3 covered blades at 195.15. For the highest efficiency: open waterwheel at 84,87%, waterwheel with 1/3 covered blades at 64,38%, waterwheel with 1/2 covered blades at 46,79%, and waterwheel with 2/3 covered blades at 33,53%. Thus, the variation in blade cover significantly affects the performance of the overshot waterwheel in terms of power, efficiency, and losses.

4. CONCLUSIONS

The maximization of kinetic energy in river flow is still widely untapped to be used as a power plant, while the need for electrical energy use continues to increase in Indonesia. Waterwheels are one of the media to generate electrical energy such as micro hydro power plants. From the experimental results, the variation of the pinwheel blade cap affects the performance of the pinwheel because the closed-top blade pinwheel is more efficient than the water wheel without a lid after all the impact loss of the water wheel with the closed blade is lower. The tangential force (Ft) increases with increasing water mass. In this study, the 1/3 closed blade waterwheel (T 1/3) is more efficient because the impact loss of the wheel (T 1/3) is lower at 720.13 when compared to the wheel without a lid (T) 1251.90 and the efficiency of the 1/3 closed blade waterwheel (T 1/3) is much higher at 64.38% when compared to the 2/3 closed blade waterwheel (T2/3) at 33.53%. Therefore, the results of this study show that the 1/3 (T 1/3) wheel is more recommended because it has a high enough efficiency and low impact losses.

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