Undershot Waterwheel Analysis Comparing Three Variations of the Laboratory Scale

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Abstract. A waterwheel is a technology that has been used by people in rural areas to lift and distribute water to a higher base than water sources. The waterwheel has a relatively simple design, large diameter, high speed and high torque. However, its application as a micro-hydro with high speed and small diameter remains to be explored. Waterwheels can operate efficiently in locations with high flow rates. The waterwheel functions from the blade of the waterwheel as a place to ride water so that the wheel can rotate.This research is an experimental study made in the form of a laboratory scale by comparing three models of blades, namely curved blades, bent blades and flat blades. The purpose of this study is to provide recommendations regarding the most appropriate type of blade to use. This research was conducted with three stages of testing, namely testing for curved, bent and flat blades. Each test of the blade model is carried out with seven variations of the flow rate which is adjusted to the cross-sectional opening of the water channel. From the results of the undershot waterwheel test by comparing three models of blades using seven variations of the same flow rate, the greatest power is found in the curved blade waterwheel, then the flat blade and the bent blade. This shows that the curved blade waterwheel is the most suitable for use.

Keywords: Undershot waterwheel, curved blade, bent blade, flat blade, laboratory scal

1. Introduction

The river is one of the aquatic ecosystems where one of its main functions is to drain water. In its utilization, river water can be channeled and used to meet the needs of people in villages such as irrigation, raw water sources, power plants and others. Of course, this utilization cannot be separated from the role of civil buildings such as weirs, embankments, dams and others so that they can be managed properly. In the irrigation area, in addition to the dam, there is also a water wheel that functions to collect river water in conditions where the river elevation is far below the land elevation. The spinning process of the waterwheel is caused by the high energy and speed of the river water flow that pushes the wheel so that it can rotate and raise the water repeatedly. If the energy and speed of river water flow is low, of course, it becomes the main problem because the wheel cannot rotate properly so that the water cannot be utilized [1].

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The need for energy in human life is increasing every year along with technological advances for both household and industrial purposes. To anticipate energy needs, many things have been done, such as processing liquid coal as a fuel to replace gasoline and diesel [2]. However, excessive dependence on non-renewable energy sources will cause several problems that must be faced, for example: the availability of these fuels is decreasing day by day until one day it will run out and cannot be renewed anymore. One thing that should also be noted is that the use of non-renewable fuels will increase the amount of carbon dioxide (CO_2) in the free air which can disrupt and pollute environmental life **[3]**.

The waterwheel is a mechanical device in the form of a wheel where there are blades around the edges. The number of blades on the water wheel also determines how much power is generated [4]. Undershot waterwheel or undercurrent waterwheel works when running water hits the blade wall located at the bottom of the waterwheel. This type is suitable for installation in shallow water on flat areas [5]. Here the flow of water is opposite to the direction of the blade that rotates the wheel. The advantages of the undershot waterwheel are: (1) simpler construction; (2) more economical; (3) easy to move while the disadvantages include: (1) small efficiency (25%-70%); (2) the power generated is relatively small [5]-[6]. The uses of water wheels from water wheels are irrigation [7]-[8]; As a pump or water distributor [9]-[10]; Hydroelectric power plant; Produce cheap and environmentally friendly electrical energy; Processing agricultural products [9].

The undershot waterwheel works when the flowing water hits the blade wall which is located at the bottom of the waterwheel. The undershot waterwheel does not have the added advantage of the head. This type is suitable for installation in shallow water on flat areas. The advantages of the undershot waterwheel are simpler construction, more economical, easy to move and can be operated on small rivers with low cutting speeds [10]-[12]. The disadvantage of the undershot waterwheel is that the efficiency and power generated is relatively small [13].

The selection of waterwheels is very dependent on conditions in the field such as head height and flow rate. The Type undershot water wheel is suitable for heads small, although this type of waterwheel in operation will experience two efficiency losses, namely inlet losses due to the geometry of the wheel and the second is frictional losses flowing through the water wheel blades [14]- [15].

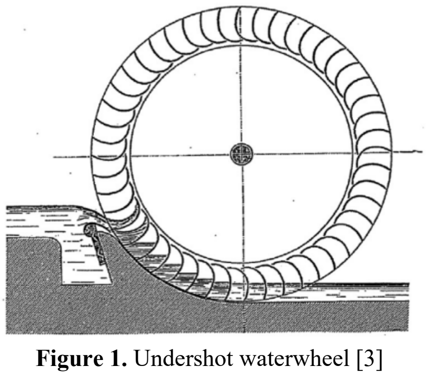

Figure 1. Undershot waterwheel [3]

The equation used is as follows:
Flow Discharge in the channel
The flow rate in the channel is the volume of water divided by time

$$Q = \frac{V}{t} \quad (1)$$

Where: Q = flow rate (m^3/s); V= volume (m^3); t = time (s)

Discharge on the Bucket

The discharge on the bucket is the volume of water produced by the bucket divided by the time

$$Q_b = \frac{Vb}{t} \quad (2)$$

Where: Q_b = discharge in bucket (m^3/s); t = time (s) and V = Bucket Volume (m^3)

Flow Velocity in channel

Flow velocity is flow rate in channel divided by surface area in channel

$$v = \frac{Q}{A} \quad (3)$$

v = flow velocity (m/s), Q = flow rate (m^3/s); A = surface area (m^2)

Water Power

Water power is the total power possessed by water that can be calculated by equation

$$P_{water} = \rho \times g \times Q \times h \quad (4)$$

Where: P_{water} = water power (watt); ρ = water density (kg/m^3), g = Gravitational acceleration (m/s^2),

Q = water flow rate (m^3/s), h = water height (m)

Kinetic Energy (Ek)

$$E_k = \frac{1}{2} \times m \times v^2 \quad (5)$$

Where: m = mass (kg) and v = flow velocity (m/s)

Fluid force hitting the blade

The fluid force hitting the blade is pressure water hitting the blade can be calculated by

$$F = \rho \times A \times v^2 \quad (6)$$

Where: F = force on the wheel (N); ρ = density of water (kg/m^3); A = surface area (m), v^2 = flow velocity (m/s)

Torque

Torque is a measure of the force that can cause an object to rotate

$$T = F \times r \quad (7)$$

Where: F = force on the wheel (N) and r = radius of the wheel (m)

Water wheel power

The power of the waterwheel is the power in circular motion which can be formulated as follows

$$P_{waterwheel} = T \times \omega \quad (8)$$

$$\omega = 2.\pi \times n$$

where: $P_{waterwheel}$ = water wheel power (watts); T = torque (Nn); = circumferential speed (rad/s); n = rotation/s

Efficiency of the waterwheel

Waterwheel efficiency is the ratio between the power generated by the waterwheel and the power generated by the water.

$$\eta = \frac{P_{waterwheel}}{P_{water}} \times 100\% \quad (9)$$

Where: η = efficiency of the waterwheel (%); $P_{waterwheel}$ = water wheel power (watts) and P_{water}= water power (watts)

2. Methodology

The tools used in the manufacture of the waterwheel consist of a stopwatch, measuring cup, ruler, water pump, grinding wheel, ring wrench, 950watt welding machine, drill, bolts and nuts, bearings, glue while the materials consist of steel and fiberglass.

The procedure for making the tool is to prepare the tools and materials for the manufacture of the tool then measure the length and width of the plate grinding plate that has been measured, after grinding the ends of the plate to form a circle using a welding machine. Measure and cut the steel for the bearing place then weld the steel to the iron plate, then install the bearing by looking at the radius of the circle so that it does not tilt when rotating. Next for the blades (flat, curved and bent) cut the fiber glass with the width and length that has been determined, for the curved blade use a 3/4pipe inch with a radius r = 20 mm then ground into 2 parts. Then for the bent blade, glue the two fibers to form a blade, then drill the plate that will be occupied by the blade, then drill the blade and attach the holder for the bolt and nut. Attach the blade to the plate then fix it using bolts and nuts.

The design of the water channel on the undershot waterwheel can be seen in the image below:

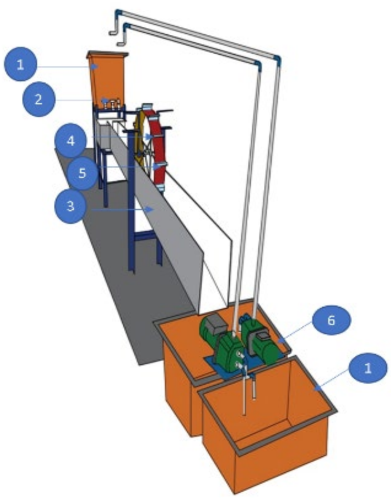

Figure 2. Laboratory scale undershot waterwheel model

Captions:

1. Water reservoir; 2. Water valve; 3. Tub on the water line; 4. Undershot waterwheel; 5. Waterways; 6. Water reservoir; 7. Water pump; 8. Water circulation pipe; 9. Cross-section of drains

Procedure for Data Collection by preparing an undershot waterwheel with a variety of blades (flat, curved and bent) that has been made; Then attach the waterwheel to the tool; Then glue it using bolts and nuts; Next test the pump; Prepare tools for data retrieval; Testing. The first thing to do for testing is filling into the reservoir for flowing water to hit the blades on the undershot waterwheel. Then measure the height of the water to be opened then when the water channel has been opened measure the depth of the water hitting the blade, after that measure the rotation of the wheel with the blade variation using a stopwatch. Then measure the flow rate that flows through the channel by holding the water that comes out through the exhaust channel by determining the predetermined time, after that measure it with a measuring cup to determine the volume of water flowing through the channel. The last stage is to measure the water discharge in the bucket by providing a measuring cup and a stopwatch, then to measure the water produced by the bucket by holding water that is lifted by the pinwheel with a predetermined time, then the water that has been in the cistern is inserted into the measuring cup. to measure the volume and discharge of the bucket.

3. Result And Discussion

After conducting experiments and data collection, the data obtained are then processed. From the research data of the water wheel undershot, data collection was carried out with a variety of blades (flat, curved and bent). In the data collection process, the number of buckets used was 8 and each measurement was taken 7 times. The water height is varied starting from 0.02 ms/d 0.14 and to support data collection, it is known that the diameter of the waterwheel (d) = 1 m; The radius of the waterwheel(r)= 0.5 m; The width of the blade of the waterwheel (l) = 0.07 m; Waterwheel blade height(t) = 0.04 m;length Bucket (p) = 0.11 m;diameter Bucket(d) = 0.007 m; distance between blades (t) = 0.21 m; the width of the wheel (l) = 0.07 m; acceleration due to gravity (g) = 9.81 m/s^2; Time (t)= 2 s; Bucket volume (Vb) = 0.00128 m^3; Volume (V) = 0.0189 m^3; wheel rotational speed (n) = 1.467 put/s; Channel width (l) = 0.15 m; Wheel radius (r) = 0.5 m

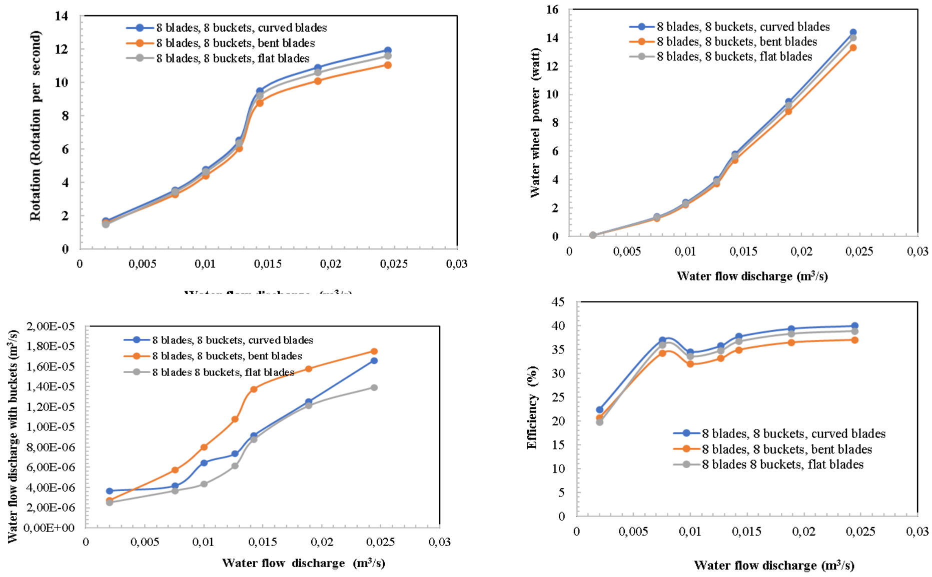

Figure 3. Graph of the relationship between (a) the flow of water to the rotation of the waterwheel; (b) the flow rate of water to the ratio between efficiency and flow of water to the power of the waterwheel; (c) the flow rate of the water to the water discharge in the bucket; (d) water flow rate on water wheel efficiency

Based on Figure .3.a. the graph of the relationship between water discharge and the rotation of the waterwheel for 3 variations of the blade (flat, curved, and bent), the results show that the greater the flow rate, the greater the rotation of the waterwheel. Of the three variations of the existing blade, the rotation produced on the curved blade is greater than the bent blade and flat plate blade. The numbers produced by the curved blade rotation are 12 rotations per second, the flat plate blade 11 rotations per second and the curved blade only 10 rotations per second obtained at a flow rate of 0.025m^3/s. This shows that the rotation of the waterwheel is directly proportional to the flow velocity.

From Figure 3.b, the relationship between water discharge and the power of the waterwheel shows that the greater the water discharge, the greater the power generated by the water wheel. This means that the power of the waterwheel is strongly influenced by the strength of the wheels and torque. While the torque is affected by the force. The strength of the waterwheel increases with increasing discharge. Based on the calculation results, the results of the waterwheel with curved blades are larger than flat plate blades and bent blades. Where the power on the curved blades obtained waterwheel power of 14.375 watts, on the curved blades obtained the power of the waterwheel of 13.310 watts and on the flat plate blades the power of the waterwheel of 13.974 watts. This shows that the curved blade of the waterwheel has greater strength compared to other water wheel blades. The third maximum power windmills are obtained at the same discharge is 0.025 m^3/ s.

Based on Figure 3.d, the turbine efficiency results are obtained from a comparison between three water wheel blades (flat, curved, and bent) with the same number of blades, namely 8 blades, the efficiency results of the curved blades have a value greater than the shape of the water wheel flat blades and bent blades. The three types of blades show that the efficiency of the waterwheel is affected by the flow velocity. The greater the flow rate, the greater the efficiency obtained. The efficiency value is obtained from the comparison of the power of the waterwheel with the power of the water. Rated maximum efficiency of 39.970% on a curved blade waterwheel with a flow rate of 0.025 m^3/ s.

In Figure 3.c the graph of the relationship between water discharge and water discharge in the bucket, it is found that the flow rate of the curved blade has a greater value than the flat plate blade and curved blade. The maximum flow rate in the three comparison results is obtained at a water discharge of 0.025 m^3/s. The value of the water discharge in the bucket on the bent blade is 1.8000E-05 m^3/s, the curved plate blade is 1.6000E-05 m^3/s and the flat plate blade is 1.2000E-05 m^3/s. The maximum water discharge is generated in the three blade variations (flat, curved and bent), namely discharge of water 0.025 m^3/ s. The discharge in the bucket will match the flow rate in the channel. The discharge in the bucket is directly proportional to the flow rate, because the greater the discharge will affect the discharge of the resulting bucket.

4. Conclution

From the results of the undershot waterwheel testing by comparing three models of blades using the same seven variations of flow rate, the greatest power is found in the curved blade, then the flat blade and the bent blade. This shows that the curved blade waterwheel is the most suitable for use.

Acknowledgments

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