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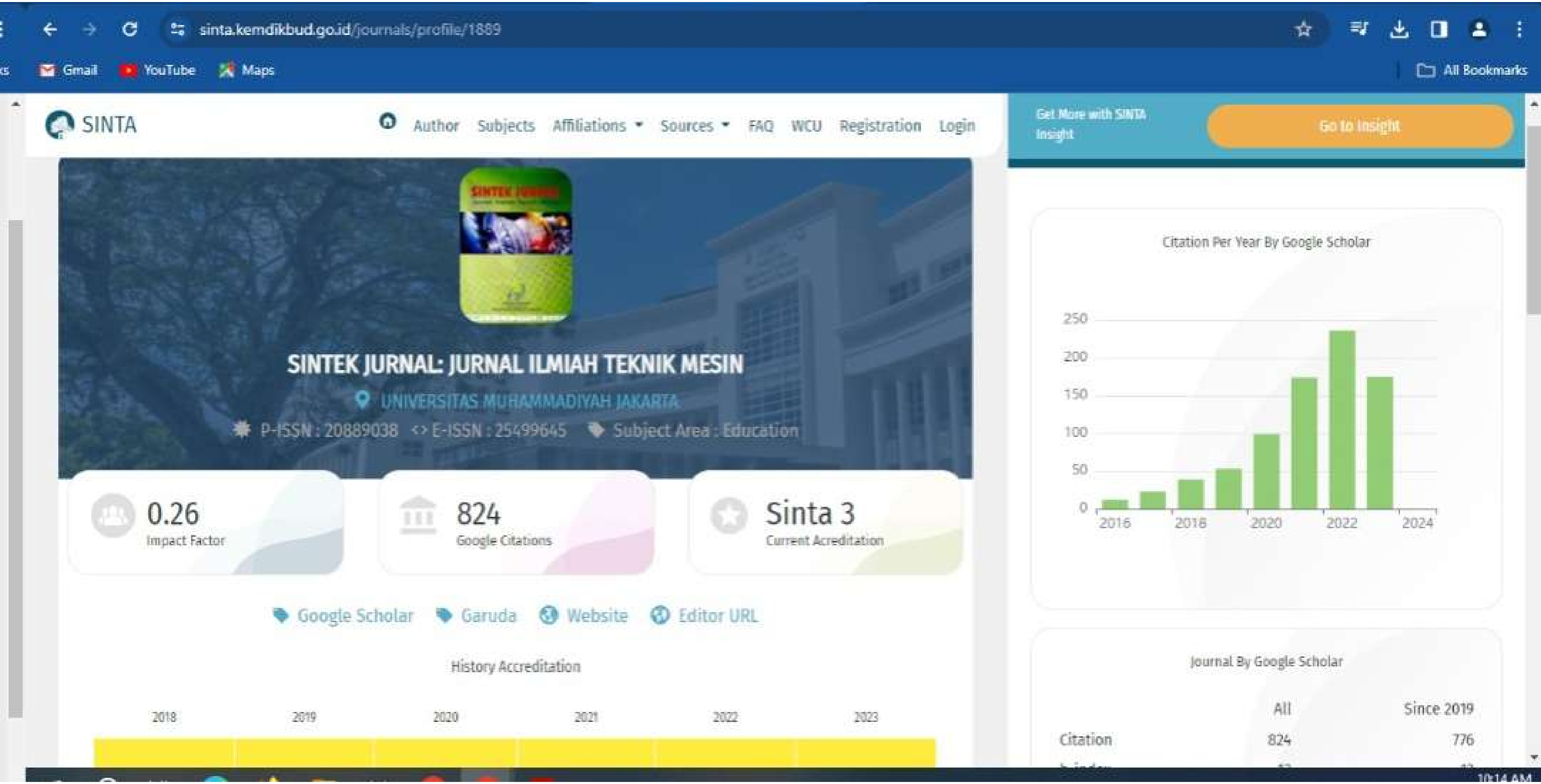
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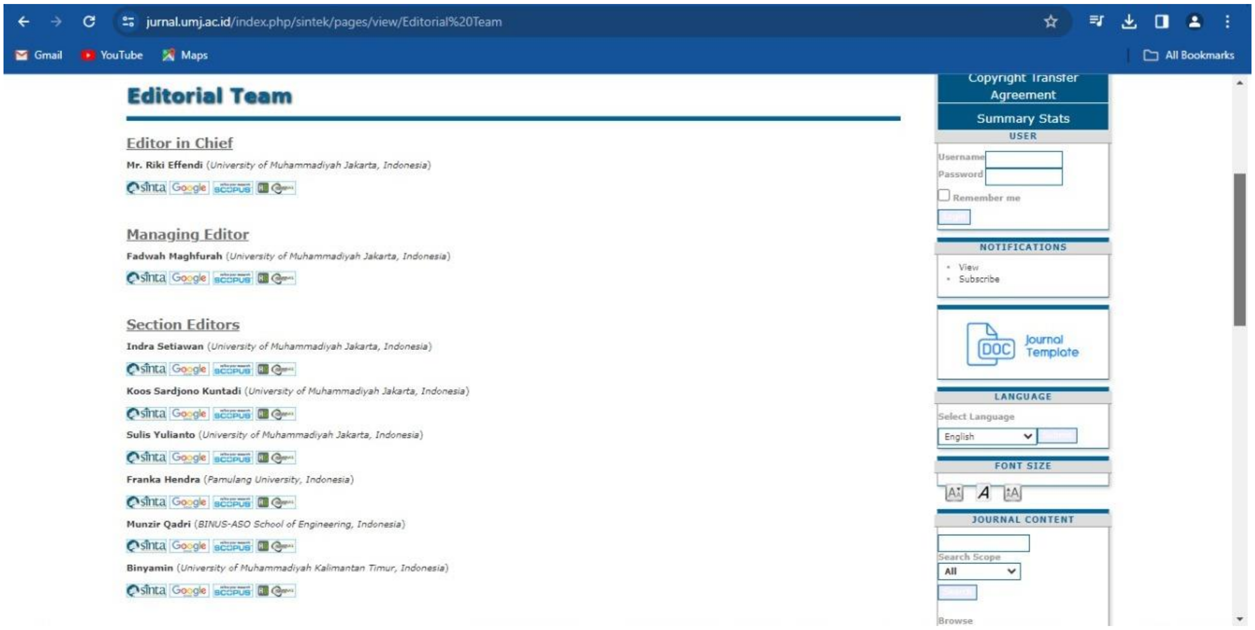

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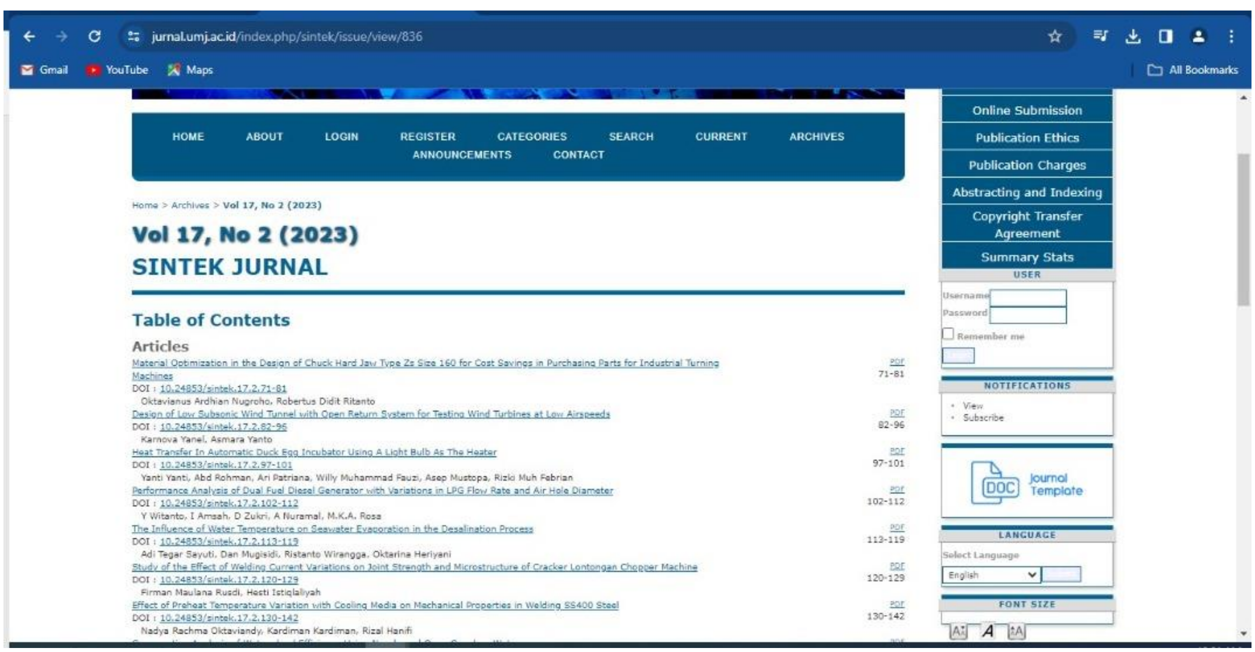

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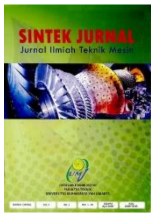

COMPARATIVE ANALYSIS OF WATERWHEEL EFFICIENCY USING NOZZLE AND OPEN CANAL ON WATERWAY

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ABSTRACT

Water flow in irrigation is a means of obtaining electric power, which is commonly called microhydro. The waterwheel is the main component of the microhydro energy conversion process. The amount of energy converted by a waterwheel depends on the shape of its model, blade shape and the location of the installer. This study aimed to identify the characteristics of optimally efficient waterwheels. In addition to the energy of the place (i.e., the head), the influence of the weight of the water flowing into the blades of the waterwheel must be considered. This study also aimed to determine the effectiveness of mill performance by comparing waterways that use nozzles with those that use open canals. An experimental method was used to design a waterwheel system by testing the efficiency ratio between the nozzle line and the open canal. This test used the following variable water discharge rates: 12 m^3/hr, 14 m^3/hr, 16 m^3/hr, 18 m^3/hr and 20 m^3/hr. Using the nozzle line with the largest discharge rate of 20 m^3/hr, an rpm of 192.7 is produced with a torque of 0.7 Nm. The waterwheel produced 14.13 Watts, with an efficiency of 64.75%. A line that used an open channel at the highest discharge rate of 20 m^3/hr produced 61.7 rpm with 0.7 Nm of torque and 4.52 Watts with an efficiency of 20.71%. The speed of water flow in the nozzle line was faster than in the open canal path, causing the tangential force on the waterwheel to be greater than on the open canal path. Based on these results, it was concluded that the path was the most efficient when using a nozzle.

Keywords: *mill power; water flow speed; efficiency.*

ABSTRAK

Aliran air pada irigasi merupakan salah satu cara untuk memperoleh tenaga listrik yang biasa disebut mikrohidro. Kincir air ini merupakan komponen utama dalam proses konversi energi tenaga mikrohidro. Jumlah energi yang dikonversi oleh kincir air tergantung pada bentuk model bladenya, dan lokasi pemasang. Tujuan dalam penelitian ini adalah untuk mengidentifikasi kincir air karakteristik yang menghasilkan efisiensi yang optimal. Faktor yang harus diperhatikan pada kincir air selain energi tempat (Head) adalah pengaruh berat air yang mengalir masuk ke sudu-sudunya. Penelitian ini bertujuan untuk mengetahui efektifitas kinerja kincir dari perbandingan antara jalur air yang menggunakan nozzle dan jalur air yang menggunakan open kanal. Metode penelitian yang digunakan adalah metode eksperimental rancang bangun sistem kincir air dengan menguji perbandingan efisiensi antara jalur nozzle dan open kanal. Pengujian ini menggunakan variabel debit air sebesar 12 m^3/jam, 14 m^3/jam, 16 m^3/jam, 18 m^3/jam, dan 20 m^3/jam, maka dari debit terbesar 20 m^3/jam jika menggunakan jalur nozzle dihasilkan rpm sebesar 192.7 dengan torsi 0.7 Nm dan daya kincir air yang dihasilkan adalah 14.13 Watt dengan efisiensi sebesar 64.75%. pada jalur yang menggunakan open kanal pada debit tertinggi 20 m^3/jam menghasilkan rpm 61.7 dengan torsi 0.7 Nm dan daya kincir air sebesar 4.52 Watt dengan efisiensi 20.71%. Maka dapat disimpulkan bahwa jalur yang lebih efisien dengan menggunakan nozzle, karena kecepatan aliran air pada jalur nozzle lebih cepat dibandingkan dengan jalur open kanal sehingga menyebabkan gaya tangensial pada kincir air lebih besar dibandingkan pada jalur open kanal.

Kata kunci: *daya kincir; kecepatan aliran air; efisiensi.*

1. INTRODUCTION

Rapid development and population growth have increased the need for electrical energy in all human activities [1]. However, the State Electricity Company (PLN) has not been able to optimise the supply of electrical energy. For example, some areas are still affected by power outages and many rural areas are not covered by the electricity network [2]. To reduce dependence on the PLN, renewable energy must be developed to optimise the amount of electrical energy in areas that have not been reached by the PLN [3]. Many innovations in all forms of power plant technology can be used to help the PLN [4] in reaching and optimising the supply of electrical energy, one of which is the microhydro power plant, which is commonly called a hydroelectric power plant [5]. The microhydro power plant is suitable for Indonesia because of the abundance of irrigation canals with a hydropower of 19 GW [6]. Microhydro power plants need to be used in areas of Indonesia that have not been reached by the electricity grid because access to electricity can allow people in an area to develop their economy.

The microhydro power plant is a small-scale power plant [7]. The waterwheel also has the advantage of being an environmentally friendly power plant because it does not require additions, such as fuel. The waterwheel is also easy to build compared with other power plants. Hydroelectric power plants use a mill as a driver and a generator as a means of converting motion (mechanical) into electrical energy [8]. This type of waterwheel moves when pushed by a flow of water; a large enough flow produces the best results [9,10]. This waterwheel is a simple device that is easy to manufacture and suitable for placing in irrigation streams [11]. There are several types of waterwheels in hydroelectric or microhydro plants, such as the overshot, breastshot and undershot [12]. The overshot waterwheel turns the waterwheel when the optimal water flow hits the upper blade of the waterwheel [13]. The breastshot waterwheel moves when the optimal water flow hits the middle blade of the waterwheel. The undershot waterwheel moves when the optimal water flow hits the bottom mill blade [14]. All three types must be adjusted to the conditions of the location of the mill because its rotation affects the initial position of the impact of water on the mill blades.

Previous studies of waterwheels have primarily examined the efficacy of open canal paths and those utilizing nozzles. Subsequent investigations of the canal path have identified substantial inefficiencies. Due to the positioning of the water fall, it only partially strikes the mill blade, with a significant volume passing through the right and left sides of the mill, leading to diminished mill efficiency. This could be reduced by adjusting the water flow, adding buckets at the end of the canal, and adjusting the width of the blades [15-21]. According to the results of previous research, the path that used a nozzle was suitable for water sources that were high enough at a low water speed but could still rotate the mill optimally [22]. This nozzle was also more efficient than turbines because it used other impulses. The thrust on the nozzle was found to be greater than that of the other types of impulses. Moreover, the position of the falling water was found to affect the efficiency of the mill [23-32]. Efficiency is an important determiner of the effectiveness of waterwheel performance and the development of waterwheel research [33]. The efficiency of the waterwheel was found to be influenced by the weight of water between the blades [34] and the impulse caused by the mass of water that drives it [35].

Therefore, the efficiency of the waterwheel is affected by how the water is drained to the mill. However, no previous study has compared waterways that use open canals and paths that use nozzles. Therefore, this study focused on comparing the efficiency of open canals and nozzles with water discharges from 12–20 m^3/hr to determine the effectiveness of performance on waterwheels [36].

2. RESEARCH METHODS

The study began by reviewing the literature on waterwheels and collecting data based on the results of previous studies on waterwheels. These data were used as a reference to determine the problematic systems found in previous research [37]. Based on the results of previous research, it was concluded that existing problems could be solved and that this research could be developed as well as possible. The study was conducted in a laboratory at the University of Muhammadiyah by Prof. Dr. Hamka. Overshot model test parameters were used in the design of the waterwheel, including the speed of the mill (RPM), discharge results and mill efficiency. This research was expected to obtain optimal results.

This study used one mill that had eight spoons with a thickness per blade of 1.5 cm and a mill diameter of 30 cm with a mill thickness of 10 cm. The mill was mounted on a mill holder with a length of 52 cm and a width of 40 cm. This stand functioned to allow the mill to be adjusted to the point of falling water. The mill holder enables the mill to be moved or to remain in one location [37].

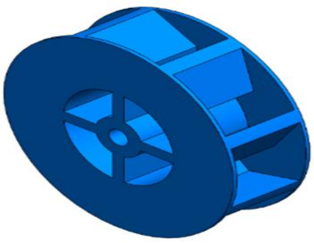

Figure 1. Waterwheel Design

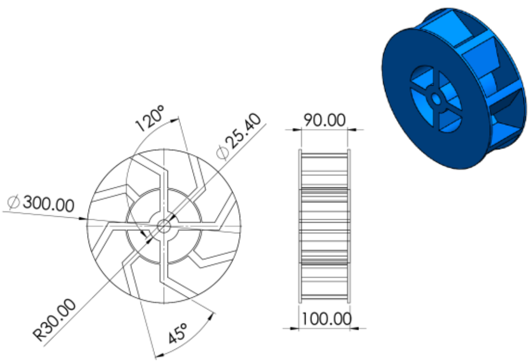

Figure 2. Waterwheel Dimensions

In this study, an artificial water tank was used as a water reservoir. A pump was used to suck the water and regulate the water discharge [38]. First, the water flowed through the rotameter, which served to determine the water discharge. After going through the rotameter, the water flowed through the end of the nozzle line or canal path and then hit the mill blade [39].

Two types of paths were used for the water flow. The first waterwheel used a nozzle, and the second waterwheel used an open canal with a width of 12 cm, a height of 10.5 cm and a length of 2 m. On this open canal path, a bucket was added so that the water could directly hit the mill blade [40], as shown in Figures 3 and 4.

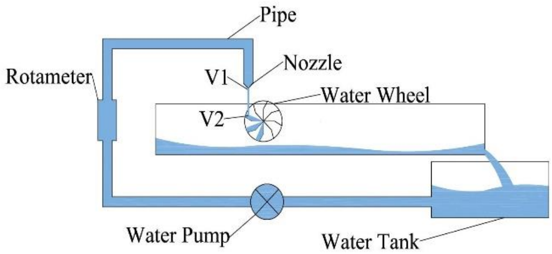

Figure 3. Nozzle Line Testing Installation

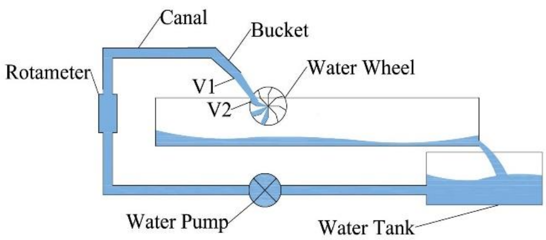

Figure 4. Open Channel Path Test Installation

Both processes used these different waterways, which were discussed in the research on variables in water discharge. The water discharge rates were 12, 14, 16, 18 and 20 m^3/hr.

The amount of power produced by the water was calculated using the following equation [41]:

$$P \ \ = \rho \times Q \times g \times H \quad (1)$$

where:
ρ = water density
Q = water debit
g = gravity
H = the height of the fall of water

The power obtained by the mill was determined by the following equation [42]:

$$P_{out} = T \times \omega \quad (2)$$
$$P_{out} = T \times \frac{2\pi N}{60}$$

where:
T = mill torque

ω = mill angular velocity
n = rotation of the mill

The efficiency was obtained by a combination of mill power and water power [43,44], using the following equation:

$$\eta = \frac{P_{water}}{P_{mill}} \times 100\% \quad (3)$$

where:
η = efficiency
P = water power
P_{out} = mill power

In a waterwheel, the force on the water (Fa) determines the tangential force of the mill (Ft), which was obtained using the following equation [45]:

$$m = \rho \times A \times v \quad (4)$$
$$Fa = m \times (v_2 - v_1)$$
$$Ft = \frac{F_a}{cos\theta}$$

where:
m = mass
A = Luas Penampang
v = Flow Speed
v2 = End Speed
v1 = Initial Speed

Several measuring instruments were used in this study to determine the speed of rotation of the mill. A torque metre was used to determine torque [46] and the Flowatch meter was used to determine the speed of the water [47], according to the specifications listed in Table 1.

Table 1. Measurement Instruments

Instrument	Type	Capacity
Tachometer	KW06-563	20–20.000 (RPM)
Torque Metre	Lutron TQ-8800	0–15 (Kg.cm)
Flow Velocity Metre	Flowatch FL-03	2–150 (Km/hr)
Rotameter	LZS 65 Z	8–40 (m3/hr)

The data were collected from the results of comparing the water flow using the nozzle line process and open canals with the addition of buckets at the end of the canal. These data were obtained from the results of tests using nozzles, as shown in Figure 5, and using open canals, as shown in Figure 6.

Figure 5. Nozzle Line Data Observation

Figure 6. Open Canal Line Observation

3. RESULTS AND DISCUSSION

The test results regarding the amount of water discharge using a nozzle and a channel path at the rates of 12, 14, 16, 18 and 20 m^3/hr are shown in Tables 2 and 3.

Table 2. Observation Data Using a Nozzle Line

Q (m3/hr)	n (rpm)	T (Nm)	V (m/s)	H (m)
12	123.8	0.7	4.01	0.40
14	140.6	0.7	4.69	0.40
16	157.8	0.7	5.35	0.40
18	173.6	0.7	6.03	0.40
20	192.7	0.7	6.70	0.40

Table 3. Observation Data Using an Open Channel

Q (m^3/hr)	n (rpm)	T (Nm)	V (m/s)	H (m)
12	30.9	0.7	0.66	0.40
14	37.4	0.7	0.78	0.40
16	47.2	0.7	0.89	0.40
18	54.4	0.7	1	0.40
20	61.7	0.7	1.11	0.40

The findings indicated that employing a 20 m^3/hr water discharge nozzle resulted in a waterwheel rotation speed of 192.7 RPM when the torque was adjusted to 0.7 Nm. Additionally, when using an open channel, the highest water discharge of 20 m^3/hr led to a mill rotation speed of 61.7 RPM with the torque set at 0.7 Nm.

The results obtained from the measuring instruments, including tip speed ratio (TSR), efficiency, mill power, water power and flow speed, [48], are shown in Tables 4 and 5.

Table 4. Observation Data on Path Using a Nozzle Line

Q (m3/jam)	Pin (W)	Pout (W)	Ft (N)	And (%)	L
12	13.07	9.08	14.56	69.47	0.48
14	15.26	10.31	22	67.56	0.47
16	17.42	11.57	30.71	66.41	0.46
18	19.62	12.74	41.01	64.93	0.45
20	21.82	14.13	52.77	64.75	0.45

Table 5. Observation Data on Path Using an Open Channel

Q (m3/jam)	Pin (W)	Pout (W)	Ft (N)	E (%)	L
12	13,07	2.27	6.64	17.36	0.73
14	15,26	2.74	6.94	17.96	0.75
16	17,42	3.46	6.99	19.86	0.83
18	19,62	3.99	6.79	20.34	0.85
20	21,82	4.52	6.39	20.71	0.87

The calculation using the largest discharge of 20 m^3/hr from the nozzle line obtained a mill power of 14.13 Watts and a flow speed of 10.97 m/s, resulting in an efficiency of 64.75%. In the open canal line, at the largest discharge of 20 m^3/hr producing a mill power of 4.52 Watts and a flow speed of 2.85 m/s, resulting in an efficiency of 20.71%. The comparison of these results is shown in Figure 7.

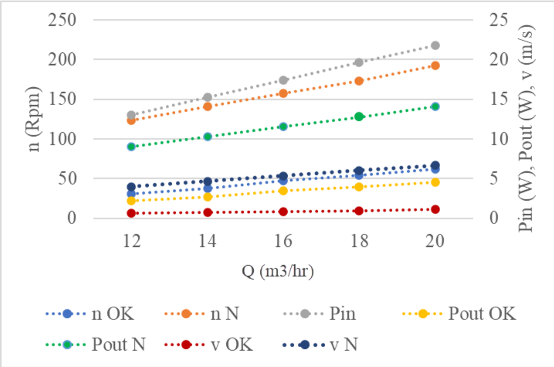

Figure 7. Graph of mill power (P_{out}), mill power (P_{in}), mill rotation speed (n), flow speed (v) and water discharge (Q)

Figure 7 shows the results of water power, mill power, mill rotation speed and flow speed. These results indicate that the greater the water discharge from 12–40 m^3/hr, the higher the flow speed and the increase in waterwheel rotation and mill power [49]. As shown in Figure 7, the path using the line nozzle (N) had the highest mill rotation, flow speed and mill power.

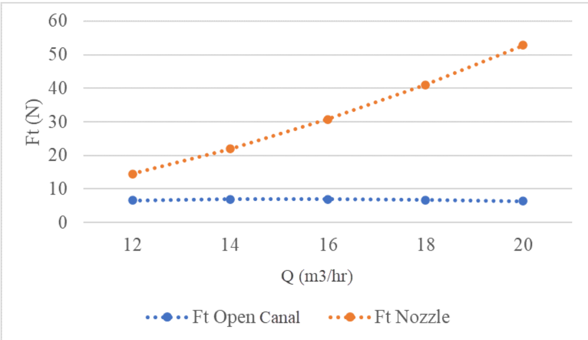

Figure 8. Tangential Force Graph (Ft)

Figure 8 shows a comparison of the results of the tangential force on the mill using the nozzle line and the open canal path. Tangential force is the water force that hits the mill, causing the waterwheel to move tangentially or perpendicularly to the track radius [50]. This force causes an increase in the power of the mill, thus affecting its efficiency. The results showed that the line nozzle path had the largest tangential force. The influence of water flow speed on the nozzle path was greater than that on the open channel path.

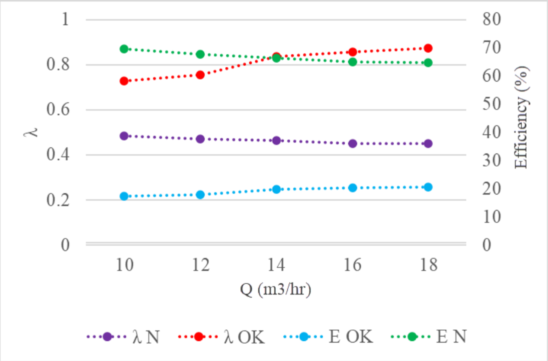

Figure 9. Efficiency Graph (%) and Tip Speed Ratio (λ)

Figure 9 shows that the efficiency produced by the nozzle line at 64.75% of the water discharge at 20 m^3/hr was greater than that of the open canal line at 20.71% of the water discharge at 20 m^3/hr. These results indicated that the nozzle line was more efficient than the open channel path. The reason is that the tangential force of the nozzle was much greater than that of the open canal. The nozzle produced a higher flow speed with the same amount of water discharge.

4. CONCLUSION

The comparison of results of the tests, observations and analysis conducted in this study on waterwheel speed, mill torque, mill power, flow speed, TSR, tangential force and mill efficiency using a nozzle line and the open channel showed that the highest mill power was produced using a nozzle of 14.13 Watts. The efficiency obtained at a water discharge of 20 m^3/hr was 64.75%, and the greatest mill power was produced with an open canal line of 4.52 Watts. The efficiency produced at a water discharge of 20 m^3/hr was 20.71%. Based on these results, it can be concluded that the highest mill power and the best efficiency were obtained using a nozzle line. The difference of the efficiency of the nozzle line and open channel was 44.04%, and the wheel power was 9.61 Watts. The reason is that the speed of water flow in the nozzle line was faster than in the open channel path, which caused the tangential force on the mill to be greater than on the open canal path.

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COMPARATIVE ANALYSIS OF WATERWHEEL EFFICIENCY USING NOZZLE AND OPEN CANAL ON WATERWAY

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ABSTRACT

Water flow in irrigation is a means of obtaining electric power, which is commonly called microhydro. The waterwheel is the main component of the microhydro energy conversion process. The amount of energy converted by a waterwheel depends on the shape of its model, blade shape and the location of the installer. This study aimed to identify the characteristics of optimally efficient waterwheels. In addition to the energy of the place (i.e., the head), the influence of the weight of the water flowing into the blades of the waterwheel must be considered. This study also aimed to determine the effectiveness of mill performance by comparing waterways that use nozzles with those that use open canals. An experimental method was used to design a waterwheel system by testing the efficiency ratio between the nozzle line and the open canal. This test used the following variable water discharge rates: 12 m^3/hr, 14 m^3/hr, 16 m^3/hr, 18 m^3/hr and 20 m^3/hr. Using the nozzle line with the largest discharge rate of 20 m^3/hr, an rpm of 192.7 is produced with a torque of 0.7 Nm. The waterwheel produced 14.13 Watts, with an efficiency of 64.75%. A line that used an open channel at the highest discharge rate of 20 m^3/hr produced 61.7 rpm with 0.7 Nm of torque and 4.52 Watts with an efficiency of 20.71%. The speed of water flow in the nozzle line was faster than in the open canal path, causing the tangential force on the waterwheel to be greater than on the open canal path. Based on these results, it was concluded that the path was the most efficient when using a nozzle.

Keywords: *mill power; water flow speed; efficiency.*

ABSTRAK

Aliran air pada irigasi merupakan salah satu cara untuk memperoleh tenaga listrik yang biasa disebut mikrohidro. Kincir air ini merupakan komponen utama dalam proses konversi energi tenaga mikrohidro. Jumlah energi yang dikonversi oleh kincir air tergantung pada bentuk model bladenya, dan lokasi pemasang. Tujuan dalam penelitian ini adalah untuk mengidentifikasi kincir air karakteristik yang menghasilkan efisiensi yang optimal. Faktor yang harus diperhatikan pada kincir air selain energi tempat (Head) adalah pengaruh berat air yang mengalir masuk ke sudu-sudunya. Penelitian ini bertujuan untuk mengetahui efektifitas kinerja kincir dari perbandingan antara jalur air yang menggunakan nozzle dan jalur air yang menggunakan open kanal. Metode penelitian yang digunakan adalah metode eksperimental rancang bangun sistem kincir air dengan menguji perbandingan efisiensi antara jalur nozzle dan open kanal. Pengujian ini menggunakan variabel debit air sebesar 12 m^3/jam, 14 m^3/jam, 16 m^3/jam, 18 m^3/jam, dan 20 m^3/jam, maka dari debit terbesar 20 m^3/jam jika menggunakan jalur nozzle dihasilkan rpm sebesar 192.7 dengan torsi 0.7 Nm dan daya kincir air yang dihasilkan adalah 14.13 Watt dengan efisiensi sebesar 64.75%. pada jalur yang menggunakan open kanal pada debit tertinggi 20 m^3/jam menghasilkan rpm 61.7 dengan torsi 0.7 Nm dan daya kincir air sebesar 4.52 Watt dengan efisiensi 20.71%. Maka dapat disimpulkan bahwa jalur yang lebih efisien dengan menggunakan nozzle, karena kecepatan aliran air pada jalur nozzle lebih cepat dibandingkan dengan jalur open kanal sehingga menyebabkan gaya tangensial pada kincir air lebih besar dibandingkan pada jalur open kanal.

Kata kunci: *daya kincir; kecepatan aliran air; efisiensi.*

1. INTRODUCTION

Rapid development and population growth have increased the need for electrical energy in all human activities [1]. However, the State Electricity Company (PLN) has not been able to optimise the supply of electrical energy. For example, some areas are still affected by power outages and many rural areas are not covered by the electricity network [2]. To reduce dependence on the PLN, renewable energy must be developed to optimise the amount of electrical energy in areas that have not been reached by the PLN [3]. Many innovations in all forms of power plant technology can be used to help the PLN [4] in reaching and optimising the supply of electrical energy, one of which is the microhydro power plant, which is commonly called a hydroelectric power plant [5]. The microhydro power plant is suitable for Indonesia because of the abundance of irrigation canals with a hydropower of 19 GW [6]. Microhydro power plants need to be used in areas of Indonesia that have not been reached by the electricity grid because access to electricity can allow people in an area to develop their economy.

The microhydro power plant is a small-scale power plant [7]. The waterwheel also has the advantage of being an environmentally friendly power plant because it does not require additions, such as fuel. The waterwheel is also easy to build compared with other power plants. Hydroelectric power plants use a mill as a driver and a generator as a means of converting motion (mechanical) into electrical energy [8]. This type of waterwheel moves when pushed by a flow of water; a large enough flow produces the best results [9,10]. This waterwheel is a simple device that is easy to manufacture and suitable for placing in irrigation streams [11]. There are several types of waterwheels in hydroelectric or microhydro plants, such as the overshot, breastshot and undershot [12]. The overshot waterwheel turns the waterwheel when the optimal water flow hits the upper blade of the waterwheel [13]. The breastshot waterwheel moves when the optimal water flow hits the middle blade of the waterwheel. The undershot waterwheel moves when the optimal water flow hits the bottom mill blade [14]. All three types must be adjusted to the conditions of the location of the mill because its rotation affects the initial position of the impact of water on the mill blades.

Previous studies of waterwheels have primarily examined the efficacy of open canal paths and those utilizing nozzles. Subsequent investigations of the canal path have identified substantial inefficiencies. Due to the positioning of the water fall, it only partially strikes the mill blade, with a significant volume passing through the right and left sides of the mill, leading to diminished mill efficiency. This could be reduced by adjusting the water flow, adding buckets at the end of the canal, and adjusting the width of the blades [15-21]. According to the results of previous research, the path that used a nozzle was suitable for water sources that were high enough at a low water speed but could still rotate the mill optimally [22]. This nozzle was also more efficient than turbines because it used other impulses. The thrust on the nozzle was found to be greater than that of the other types of impulses. Moreover, the position of the falling water was found to affect the efficiency of the mill [23-32]. Efficiency is an important determiner of the effectiveness of waterwheel performance and the development of waterwheel research [33]. The efficiency of the waterwheel was found to be influenced by the weight of water between the blades [34] and the impulse caused by the mass of water that drives it [35].

Therefore, the efficiency of the waterwheel is affected by how the water is drained to the mill. However, no previous study has compared waterways that use open canals and paths that use nozzles. Therefore, this study focused on comparing the efficiency of open canals and nozzles with water discharges from 12–20 m^3/hr to determine the effectiveness of performance on waterwheels [36].

2. RESEARCH METHODS

The study began by reviewing the literature on waterwheels and collecting data based on the results of previous studies on waterwheels. These data were used as a reference to determine the problematic systems found in previous research [37]. Based on the results of previous research, it was concluded that existing problems could be solved and that this research could be developed as well as possible. The study was conducted in a laboratory at the University of Muhammadiyah by Prof. Dr. Hamka. Overshot model test parameters were used in the design of the waterwheel, including the speed of the mill (RPM), discharge results and mill efficiency. This research was expected to obtain optimal results.

This study used one mill that had eight spoons with a thickness per blade of 1.5 cm and a mill diameter of 30 cm with a mill thickness of 10 cm. The mill was mounted on a mill holder with a length of 52 cm and a width of 40 cm. This stand functioned to allow the mill to be adjusted to the point of falling water. The mill holder enables the mill to be moved or to remain in one location [37].

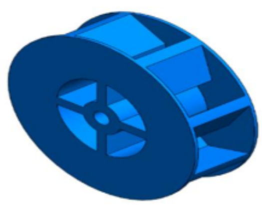

Figure 1. Waterwheel Design

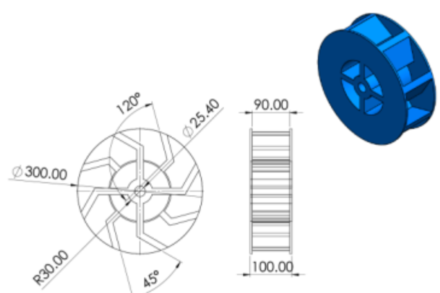

Figure 2. Waterwheel Dimensions

In this study, an artificial water tank was used as a water reservoir. A pump was used to suck the water and regulate the water discharge [38]. First, the water flowed through the rotameter, which served to determine the water discharge. After going through the rotameter, the water flowed through the end of the nozzle line or canal path and then hit the mill blade [39].

Two types of paths were used for the water flow. The first waterwheel used a nozzle and the second waterwheel used an open canal with a width of 12 cm, a height of 10.5 cm and a length of 2 m. On this open canal path, a bucket was added so that the water could directly hit the mill blade [40], as shown in Figures 3 and 4.

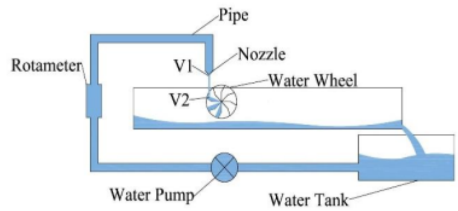

Figure 3. Nozzle Line Testing Installation

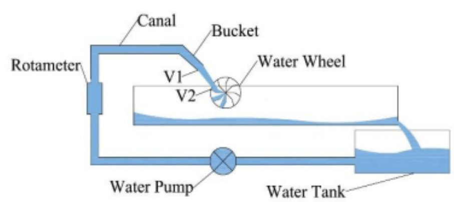

Figure 4. Open Channel Path Test Installation

Both processes used these different waterways, which were discussed in the research on variables in water discharge. The water discharge rates were 12, 14, 16, 18 and 20 m^3/hr.

The amount of power produced by the water was calculated using the following equation [41]:

$$P = \rho \times Q \times g \times H \quad (1)$$

where:
ρ = water density
Q = water debit
g = gravity
H = the height of the fall of water

The power obtained by the mill was determined by the following equation [42]:

$$P_{out} = T \times \omega \quad (2)$$
$$P_{out} = T \times \frac{2\pi N}{60}$$

where:
T = mill torque

ω = mill angular velocity
n = rotation of the mill

The efficiency was obtained by a combination of mill power and water power [43,44], using the following equation:

$$\eta = \frac{P_{water}}{P_{mill}} \times 100\% \quad (3)$$

where:
η = efficiency
P = water power
P_{out} = mill power

In a waterwheel, the force on the water (Fa) determines the tangential force of the mill (Ft), which was obtained using the following equation [45]:

$$m = \rho \times A \times v \quad (4)$$
$$Fa = m \times (v_2 - v_1)$$
$$Ft = \frac{F_a}{cos\theta}$$

where:
m = mass
A = Luas Penampang
v = Flow Speed
v2 = End Speed
v1 = Initial Speed

Several measuring instruments were used in this study to determine the speed of rotation of the mill. A torque metre was used to determine torque [46] and the Flowatch meter was used to determine the speed of the water [47], according to the specifications listed in Table 1.

Table 1. Measurement Instruments

Instrument	Type	Capacity
Tachometer	KW06-563	20–20.000 (RPM)
Torque Metre	Lutron TQ-8800	0–15 (Kg.cm)
Flow Velocity Metre	Flowatch FL-03	2–150 (Km/hr)
Rotameter	LZS 65 Z	8–40 (m3/hr)

The data were collected from the results of comparing the water flow using the nozzle line process and open canals with the addition of buckets at the end of the canal. These data were obtained from the results of tests using nozzles, as shown in Figure 5, and using open canals, as shown in Figure 6.

Figure 5. Nozzle Line Data Observation

Figure 6. Open Canal Line Observation

3. RESULTS AND DISCUSSION

The test results regarding the amount of water discharge using a nozzle and a channel path at the rates of 12, 14, 16, 18 and 20 m^3/hr are shown in Tables 2 and 3.

Table 2. Observation Data Using a Nozzle Line

Q (m3/hr)	n (rpm)	T (Nm)	V (m/s)	H (m)
12	123.8	0.7	4.01	0.40
14	140.6	0.7	4.69	0.40
16	157.8	0.7	5.35	0.40
18	173.6	0.7	6.03	0.40
20	192.7	0.7	6.70	0.40

Table 3. Observation Data Using an Open Channel

Q (m^3/hr)	n (rpm)	T (Nm)	V (m/s)	H (m)
12	30.9	0.7	0.66	0.40
14	37.4	0.7	0.78	0.40
16	47.2	0.7	0.89	0.40
18	54.4	0.7	1	0.40
20	61.7	0.7	1.11	0.40

The findings indicated that employing a 20 m^3/hr water discharge nozzle resulted in a waterwheel rotation speed of 192.7 RPM when the torque was adjusted to 0.7 Nm. Additionally, when using an open channel, the highest water discharge of 20 m^3/hr led to a mill rotation speed of 61.7 RPM with the torque set at 0.7 Nm.

The results obtained from the measuring instruments, including tip speed ratio (TSR), efficiency, mill power, water power and flow speed, [48], are shown in Tables 4 and 5.

Table 4. Observation Data on Path Using a Nozzle Line

Q (m3/jam)	Pin (W)	Pout (W)	Ft (N)	And (%)	L
12	13.07	9.08	14.56	69.47	0.48
14	15.26	10.31	22	67.56	0.47
16	17.42	11.57	30.71	66.41	0.46
18	19.62	12.74	41.01	64.93	0.45
20	21.82	14.13	52.77	64.75	0.45

Table 5. Observation Data on Path Using an Open Channel

Q (m3/jam)	Pin (W)	Pout (W)	Ft (N)	E (%)	L
12	13,07	2.27	6.64	17.36	0.73
14	15,26	2.74	6.94	17.96	0.75
16	17,42	3.46	6.99	19.86	0.83
18	19,62	3.99	6.79	20.34	0.85
20	21,82	4.52	6.39	20.71	0.87

The calculation using the largest discharge of 20 m^3/hr from the nozzle line obtained a mill power of 14.13 Watts and a flow speed of 10.97 m/s, resulting in an efficiency of 64.75%. In the open canal line, at the largest discharge of 20 m^3/hr producing a mill power of 4.52 Watts and a flow speed of 2.85 m/s, resulting in an efficiency of 20.71%. The comparison of these results is shown in Figure 7.

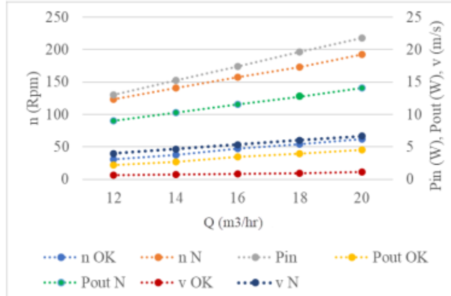

Figure 7. Graph of mill power (P_{out}), mill power (P_{in}), mill rotation speed (n), flow speed (v) and water discharge (Q)

Figure 7 shows the results of water power, mill power, mill rotation speed and flow speed. These results indicate that the greater the water discharge from 12–40 m^3/hr, the higher the flow speed and the increase in waterwheel rotation and mill power [49]. As shown in Figure 7, the path using the line nozzle (N) had the highest mill rotation, flow speed and mill power.

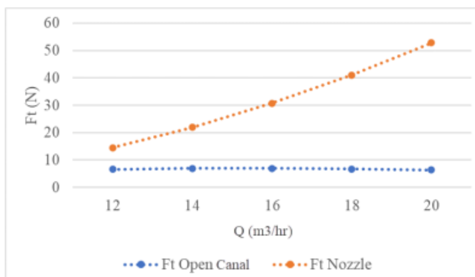

Figure 8. Tangential Force Graph (Ft)

Figure 8 shows a comparison of the results of the tangential force on the mill using the nozzle line and the open canal path. Tangential force is the water force that hits the mill, causing the waterwheel to move tangentially or perpendicularly to the track radius [50]. This force causes an increase in the power of the mill, thus affecting its efficiency. The results showed that the line nozzle path had the largest tangential force. The influence of water flow speed on the nozzle path was greater than that on the open channel path.

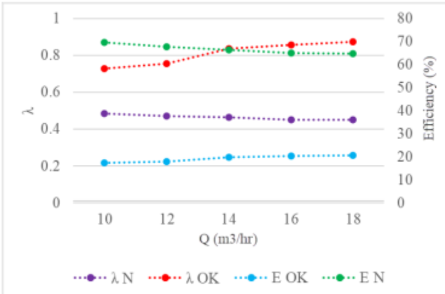

Figure 9. Efficiency Graph (%) and Tip Speed Ratio (λ)

Figure 9 shows that the efficiency produced by the nozzle line at 64.75% of the water discharge at 20 m^3/hr was greater than that of the open canal line at 20.71% of the water discharge at 20 m^3/hr. These results indicated that the nozzle line was more efficient than the open channel path. The reason is that the tangential force of the nozzle was much greater than that of the open canal. The nozzle produced a higher flow speed with the same amount of water discharge.

4. CONCLUSION

The comparison of results of the tests, observations and analysis conducted in this study on waterwheel speed, mill torque, mill power, flow speed, TSR, tangential force and mill efficiency using a nozzle line and the open channel showed that the highest mill power was produced using a nozzle of 14.13 Watts. The efficiency obtained at a water discharge of 20 m^3/hr was 64.75%, and the greatest mill power was produced with an open canal line of 4.52 Watts. The efficiency produced at a water discharge of 20 m^3/hr was 20.71%. Based on these results, it can be concluded that the highest mill power and the best efficiency were obtained using a nozzle line. The difference of the efficiency of the nozzle line and open channel was 44.04%, and the wheel power was 9.61 Watts. The reason is that the speed of water flow in the nozzle line was faster than in the open channel path, which caused the tangential force on the mill to be greater than on the open canal path.

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