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## Article

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# The effect of wheel and nozzle diameter ratio on the performance of a Turgo turbine with pico scale

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## Abstract

A Turgo turbine with a pico scale (<5 kW) is one solution to supplying electrical energy in remote areas because of its low construction costs and ease of maintenance. Based on empirical equations, the ratio of the wheel ( $D$ ) and nozzle diameter ( $d$ ), or  $D/d$ , of a Turgo turbine must be determined precisely because it affects wheel velocity, which has an impact on performance and/or efficiency. However, the optimum  $D/d$  ratio has not yet been clearly determined. To find the optimum  $D/d$  ratio for a Turgo turbine with a pico scale that can produce maximum electrical power, this study will examine five variations of the  $D/d$  ratio: 11.6, 13.8, 14.7, 22 and 27.5. In order for this turbine to be implemented in remote areas, coconut shell is proposed as the material for its blades. The results of the analysis, which used a one-way analysis of variance (ANOVA) test with a confidence level of 92.5%, show that the  $D/d$  ratio had a significant influence on performance. Based on the results, a  $D/d$  ratio of 22 produces the highest efficiency – 34.97% with an electric power of 5.34 W (13.21 Vdc  $\pm$  0.1 Vdc and 396.4 mA  $\pm$  7.46 mA) – compared to the other ratios. Thus, the pico-scale Turgo turbine runner design is optimized at the  $D/d$  ratio of 22. Furthermore, coconut shell blades can be implemented for a pico-scale Turgo turbine.

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**Keywords:** Pico hydro; Turgo turbine; Wheel; Nozzle; Remote areas

## 1. Introduction

Supplying electrical energy to remote areas, even with the expansion of national electricity networks, is still difficult because of natural factors, as such areas are often hilly regions without adequate infrastructure access. Furthermore, the expansion of an electricity network into remote areas can make the price of electricity uneconomical because the areas often have small populations with lower incomes than urban communities [1]. One solution to supplying electricity needs to remote areas with hilly regions that possess a water source is pico hydro technology (<5 kW), the investment and maintenance costs of which are lower than for wind turbine and solar PV

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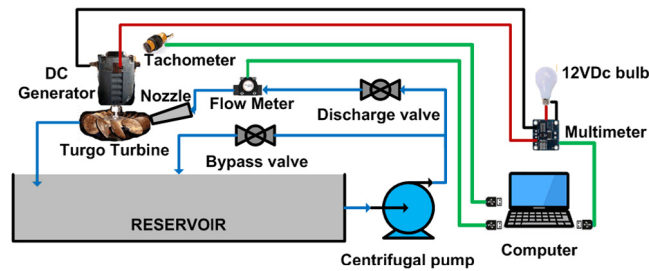


Fig. 1. Experiment setup.

technologies [2,3]. In pico hydro applications for remote areas, the Turgo type impulse turbine is recommended for use because of its low construction costs and ease of maintenance [4].

Turgo turbines are categorized as impulse turbines because they utilize the kinetic energy of water ( $EK$ ) to rotate their shafts. The development of Turgo turbine capability in pico hydro applications has been studied. Williamson et al. [5] designed a pico hydro Turgo turbine with a two-dimensional quasi-steady-state equation to predict its performance characteristics and identify critical parameters in experiments. In another study, Cobb and Sharp [6] examined the hypothesis that pico hydro Turgo turbine efficiency is affected by the ratio of its runner speed to the nozzle as well as the Pelton turbine and that the nozzle attack angle must be minimized to capture maximum energy transfer. Gaiser et al. [7] designed Turgo turbines at a low capital cost using stainless steel tablespoons, while Warjito et al. [8] designed Turgo turbines for pico hydro applications with a simple bucket curvature. Budiarso et al. [9] simplified the Turgo buckets using stainless steel rice spoons along with nozzles using  $3/4$  inch PVC pipe to reduce the pico hydro capital cost in remote areas.

The analysis concept of the dimensions of a Turgo turbine is mostly adopted from the Pelton turbine. Not surprisingly, the results of previous studies are similar to the conditions of Pelton turbine performance. Based on Pelton turbine empirical equations, the ratio of wheel diameter ( $D$ ) with nozzle diameter ( $d$ ), or  $D/d$ , must be determined precisely because it affects the wheel velocity, which has an impact on performance and/or efficiency [10]. This also applies to the Turgo turbine. Thus, the  $D/d$  ratio must be in the correct range so that the turbine operates at its highest efficiency.

Numerous studies have been conducted to obtain the optimal diameter ratio. Cobb and Sharp [6] examined turbine testing in the  $D/d = 15.2\text{--}21.3$  for a runner diameter of 169 mm and  $D/d = 10.3\text{--}16.5$  for a runner diameter of 131 mm ranges. Experiments conducted by Williamson et al. [5] showed that the ratio  $D/d = 7.5$  with a range of usage ratio diameter  $D/d = 5\text{--}10$  resulted in the best efficiency. Using response surface methodology, Gaiser et al. [7] obtained the optimum diameter ratio  $D/d = 8.5$ . Although studies of the influence of diameter ratios on the performance of the Turgo turbine have been conducted, they have not produced similar results. In addition, the pico hydro Turgo turbine is a low cost turbine, but few studies on the uses of simple materials have been conducted.

This study will analyse a pico hydro Turgo turbine constructed of simple materials with a correct  $D/d$  ratio. It will be conducted with experiments employing several  $D/d$  ratios using PVC and aluminium pipes as simple nozzle materials. The purpose of this study is to determine the ratio of  $D/d$  for a pico hydro Turgo turbine that can produce maximum electric power.

## 2. Materials and methods

The material used for the Turgo runner is a locally sourced coconut shell spoon with a diameter of 220 mm. The coconut shell spoons are used as buckets connected to a wooden hub. The runner is connected directly to the generator without a transmission by using shaft support. The nozzles used are standard PVC and aluminium pipes with diameters of 8, 10, 15, 16 and 19 mm.

Experimental testing was conducted that measured the parameters of a power plant system that affected performance, such as discharge ( $Q$ ), rotational speed ( $n$ ), voltage direct current ( $Vdc$ ) and current ( $I$ ). This experiment uses a single pipe system with reservoir, discharge valve (a ball valve) and a centrifugal pump. The head available on the nozzle is varied using the bypass valve, as shown in Fig. 1.

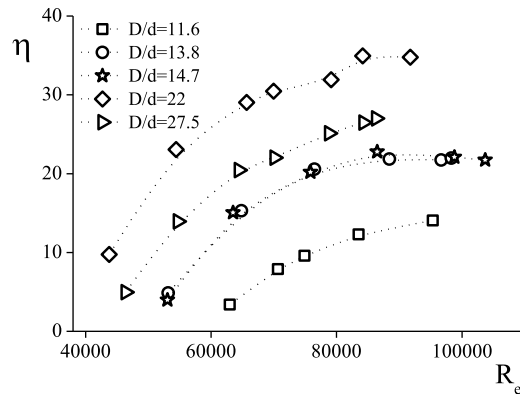


Fig. 2. Relationship of Turgo turbine efficiency and Reynolds number with  $D/d$  ratio.

A DC generator was used because it is able to produce electric power at low speeds [11]. The load uses a DC bulb with 12Vdc specifications. The measuring equipment uses a flow metre to measure the  $Q$  of the sprayed nozzle, a tachometer to measure the  $n$  of the turbine and a multimeter to measure the  $Vdc$  and  $I$  produced by the DC generator. The discharge ( $Q$ ) is varied by varying the opening of the bypass valve (see Fig. 1). Furthermore, the  $Q$  parameters will be used to determine the available hydraulic power, as in Eq. (1):

$$P_j = 3.75 Q^3 / d^4 \quad (1)$$

Before determining efficiency ( $\eta$ ) using Eq. (3), the electrical power must be found with Eq. (2):

$$P_e = Vdc \cdot I \quad (2)$$

$$\eta = P_e / P_j \quad (3)$$

The data obtained is not directly processed; the data must be filtered to reject that is categorized as will point [12]. Chauvenet's criterion is applied to reject data. Furthermore, the measuring instruments used (multimeter, tachometer and flow metre) have an error of  $<5\%$  than commercial measuring devices and an uncertainty of 1%. Before determining the optimum  $D/d$ , a one-way analysis of variance (ANOVA) test was conducted to determine whether the  $D/d$  ratio influenced performance. A probability of 92.5% is used in a one-way ANOVA test. Microsoft Excel was used for the one-way ANOVA testing.

### 3. Results and discussions

#### 3.1. Results

The performance of the Turgo turbine is expressed by efficiency, as shown in Fig. 2. Based on the results, the Turgo turbine requires a minimum rotational speed of approximately 200 rpm to the generator to produce a current that turns the bulb on. The variable velocity jet and nozzle diameter are not the same value for each test condition; they are uniformed using the Reynolds number ( $Re$ ), which is a function of velocity jet and nozzle diameter. In all variations, the efficiency increases if the Reynolds number increases (hydraulic power increases). The efficiency will continue to increase until the resulting voltage reaches 12 Vdc, after which it will decrease. Based on Fig. 2, the  $D/d$  ratio of 11.6 yielded the maximum efficiency of 14.7%, 13.8 yielded 21.87%, 14.7 22.79%, 22 34.97%, and 27.5 26.99%.

According to the literature, to obtain optimum performance from a Turgo turbine, the  $D/d$  ratio must be in the range of 11 to 16 [10]. This ratio seems to be intended for normal-scaled hydropower turbines such as in mini-hydro, medium, and large hydropower plant. Hence in the test results, the  $D/d$  ratio of 22 resulted in higher efficiency compared to the others: the  $D/d$  ratios of 11 to 16 do not seem appropriate for application to a pico-scale Turgo turbine. Furthermore, the results of the calculation analysis using the one-way ANOVA test concluded that  $F > F_{crit}$ , which means that the  $D/d$  ratio has an influence on performance (see Table 1). Table 1 is a summary analysis of the calculations made by the one-way ANOVA with a 92.5% level of probability.

**Table 1.** Summary of calculation results using one-way ANOVA test.

Source of variation	SS	df	MS	F	P-value	$F_{crit}$
Variations of D/d ratio	593.98527	4	148.49632	2.681841	0.061292	2.501731
Error	1107.4207	20	55.371037	–	–	–
Total	1701.406	24	–	–	–	–

### 3.2. Discussions

The ratio between the runner diameter to the nozzle diameter used in this study is the result of the use of nozzle materials which are widely available in the market. An advantage of pico hydro applications is their low cost and easily obtained materials [13], which are the reasons for using PVC and aluminium pipes in this study. Besides being widely available, their price is relatively affordable compared to using a nozzle arrangement.

Table 1 shows, statistically, that the  $D/d$  ratio has a significant effect on performance. Based on the results, the  $D/d$  ratio of 22 produces the highest efficiency, indicating that the optimum  $D/d$  ratio for Turgo turbines in pico scale is 22. The  $D/d$  of 22 has a higher efficiency because the magnitude (velocity), amount (discharge) and direction (vector) of water jet produced are proportional to losses. The  $D/d$  of 27.5 produces the highest magnitude (velocity) of the water jet, but the resulting discharge is the lowest compared to the others. Even though the direction and magnitude are a benefit, a low discharge is produced due to high losses.

The experimental results obtained are similar to the results of Williamson et al. [5], where the jet diameter ( $d$ ) has an influence on performance. Although it is capable of producing twice the efficiency, the diameter of the wheel used in [5] was smaller than the one used in this study. The smaller diameter will certainly create complications in terms of manufacturing. Moreover, the tool used to make the blades used in the Williamson study, a three-dimensional (3D) printer, is high-tech and is very unlikely to be available in remote communities, especially in Indonesia. Thus, the results of this study can be applied to remote areas with little or no access to electrical energy.

### 4. Conclusion

The  $D/d$  ratio is one of the important parameters in designing Turgo turbines. The results show that the Turgo turbine runner design is optimum at the  $D/d$  ratio of 22. This is because it produces the highest efficiency of 34.97% with an electric power of 5.34 W (13.21 Vdc  $\pm$  0.1 Vdc and 396.4 mA  $\pm$  7.46 mA). Furthermore, the proposed blade design is easily manufactured and repaired because the raw material (coconut shell) is available in many remote areas, especially in Indonesia.

### Acknowledgement

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