

Adanta, Dendy; Budiarmo; Warjito

## Article

# The effect of channel slope angle on breastshot waterwheel turbine performance by numerical method

Energy Reports

**Provided in Cooperation with:**

Elsevier

*Suggested Citation:* Adanta, Dendy; Budiarmo; Warjito (2020) : The effect of channel slope angle on breastshot waterwheel turbine performance by numerical method, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, Iss. 2, pp. 606-610, <https://doi.org/10.1016/j.egyr.2019.11.126>

This Version is available at:

<https://hdl.handle.net/10419/243939>

### Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

### Terms of use:

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

The 6th International Conference on Power and Energy Systems Engineering (CPESE 2019),  
20–23 September 2019, Okinawa Japan

# The effect of channel slope angle on breastshot waterwheel turbine performance by numerical method

Dendy Adanta, Budiarsa, Warjito\*

*Departement of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, 16424, Indonesia*

Received 14 October 2019; accepted 23 November 2019

---

## Abstract

This study examined the effect of the water channel slope angle on breastshot waterwheel turbine performance using the computational fluid dynamics method with six-degrees of freedom (6-DoF) feature. The method and 6-DoF feature were chosen because turbine rotation is a computational result and the flow pattern can be represented more precisely. Computational results using the 6-DoF feature were used as the basis for recommending a ratio of rotational velocity for a wheel ( $U$ ) with an inlet velocity ( $W$ ), or  $U/W$ , for turbine design. Five slope angles were analysed, and the results indicated higher efficiency was produced by a  $10^\circ$  slope angle while the lowest was  $25^\circ$ . Based on results, a higher slope angle channel could cause losses or leakage due to water leading to a gap between the wheel and channel. As such, a method of increasing the kinetic energy of water by modifying the channel shape, such as having an angle, requires additional attention to the water velocity direction. Moreover, stable efficiency occurs in a ratio of  $U/W$  between 1.1 - 1.6. Thus, it is estimated that the optimum turbine design recommended for  $U$  being 1.1 to 1.6 times  $W$ .

© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

*Keywords:* Breastshot; Waterwheel; Computational

---

## 1. Introduction

The breastshot waterwheel is one of the oldest types of pico hydro turbine technology, but the development of research at the beginning of the 21st century. The breastshot waterwheel uses a bucket in the middle to absorb energy into the shaft to produce electricity [1]. In the 21st century, most development research has been performed using the computational fluid dynamics (CFD) method and breastshot turbines are no exception. Among the topics of breastshot waterwheel research completed using CFD methods are the physical phenomena of the fluid [2–4], the influence of a turbulent model on prediction results using CFD method [3,4], losses that improve the bucket shape [2,5], the influence of wheel rotational speed ( $n$ ) on performance [1], the effect of the number of blades [3,4],

---

\* Corresponding author.

*E-mail address:* [warjito@eng.ui.ac.id](mailto:warjito@eng.ui.ac.id) (Warjito).

the contribution of the kinetic energy of water to the power being produced [2–4] and the breastshot waterwheel characteristics that relate to power losses [6].

From these topics, several conclusions have been obtained. First, turbulent models for breastshot waterwheel turbines use shear stress transport  $k-\omega$  [7] or standard  $k-\omega$  [2]. Based on the results, shear stress transport  $k-\omega$  is more precise because turbulent viscosity is analysed in greater detail than with standard  $k-\omega$ , but it also requires greater computing power [8]. Therefore, this study used a standard  $k-\omega$  turbulence model to simplify the calculation process. Second, determining the number of blades remains an optimisation method [3,4] and still requires a comprehensive study to propose empirical equations that facilitate the application in certain conditions. Third, the discussion about the effect of the kinetic energy ( $EK$ ) of water into performance is ongoing, since analysis of variance testing with a confidence level of 90% concluded that  $EK$  has a significant effect while using a 95% level found there was no  $EK$  effect on performance [2]. Despite this, current views hold that  $EK$  has an influence [1,3,4].

To prove that  $EK$  influences performance, this study will vary the shape of the water channel before examining the wheel using CFD methods with a six-degrees of freedom feature (6-DoF) (see Fig. 1). The 6-DoF feature was used because the rotation of wheel is not a boundary condition but the result of computation. Furthermore, this feature is capable of predicting flow patterns better than moving mesh for engine power. The computational results using the 6-DoF feature will also be the basis for recommending an optimum ratio of the rotational velocity of wheel ( $U$ ) with the inlet velocity ( $W$ ), or  $U/W$ , for turbine design. Thus, this study will examine the effect of the water channel's slope angle on the performance of a breastshot waterwheel turbine, specifically the power generated, using the CFD method with a 6-DoF feature, and recommending the optimum  $U/W$  ratio for turbine design.

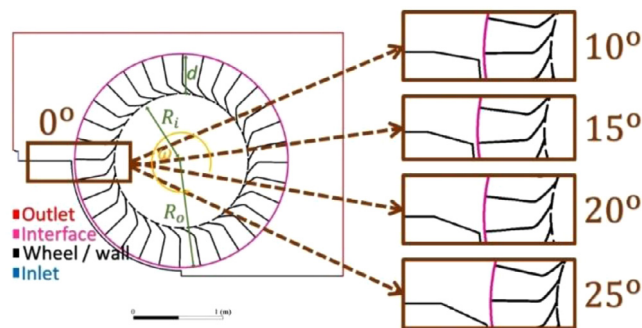


Fig. 1. Geometry design.

## 2. Methodology

### 2.1. Geometry

This study is a follow-up study that will use the following main parameters [2]: radius outer ( $R_o$ ) = 1.04 m; radius inner ( $R_i$ ) = 0.67 m; annulus ( $d$ ) = 0.37 m; angular speed ( $\omega$ ) = 10.31 rpm; width ( $B$ ) = 0.25 m; and inlet height ( $t$ ) = 0.05 m. The representation of the main parameters and the variations of the slope angle to be analysed can be seen in Fig. 1. A detailed geometry analysis can be accessed in the previous study [2].

### 2.2. CFD methods

Computational calculations will be performed using commercial software CFD i.e. ANSYS Fluent 18.1™ with two-dimensional analysis and 6-DoF feature. Such analysis is considered representative for predictions of flow pattern and the performance of the breastshot waterwheel turbine [1,2].

The simulation will be divided into three stages: pre-processing, processing and post-processing. Pre-processing consists geometric name selecting (such as inlet, outlet, interface wheel, interface interior, wheel and wall (see Fig. 1), as well as the interface wheel and interface interior being joined so that software does not consider the interface to be a wall), meshing and determining boundary conditions. Among those conditions will be a pressure

inlet of 490 Pa (the standard  $k-\omega$  turbulent model was chosen because resulting prediction is quite representative [2], an inertia moment of 125 N m (obtained with computer-aided design software), a preload of 18.75 N m, an activation of the volume of fraction model with friction stress between water and air assumed at 0.0728 N m, a rotating and re-meshing activation used for mesh changes in size to adjust to the initial conditions and smoothing selected to repair–improve the mesh size.

Upon determining all boundary conditions, the grid convergence index (GCI) analysis, or mesh independency test, will be completed. The GCI will determine the optimum mesh number to be used. The concept of calculating the GCI can be seen in a previous study [9]. As no method for determining an optimum time step size exists presently, the GCI analysis concept will be adopted to a timestep independency test.

### 3. Results and discussions

#### 3.1. Results

To ensure the mesh number and time step are optimal for use, a convergence analysis was performed using the GCI concept. Fig. 2 shows a summary of the convergence calculations for both mesh number and the time step size. Variations in the mesh number were analysed: 30,190 elements were normalised to 4.04; 123,031 elements to 2; and 493,483 elements to 1. Based on GCI analysis, the largest mesh number was used due to it having an error rate of 0.22% against the exact value its. Variations in the time step frequency were then analysed: 125 Hz were normalised to 2; 250 Hz to 1.44; and 500 Hz to 1. Based on the timestep convergence index (TCI), the timestep frequency of 500 Hz, or size of 0.002 s, was used with an error rate of 3.12% against its exact value.

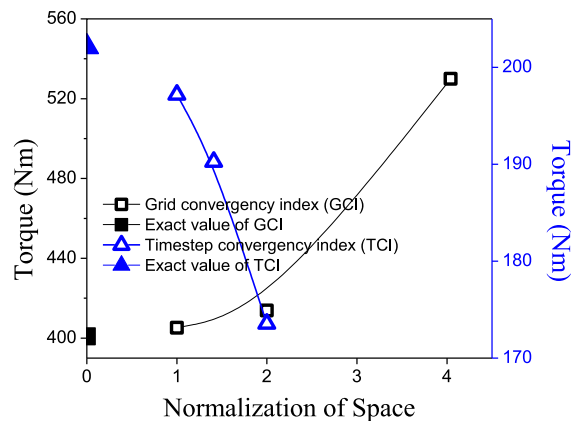


Fig. 2. Results of convergence analysis.

Fig. 3 displays graphic patterns of simulation results similar to the results of previously conducted experiments [10,11], where turbines had optimum operational conditions. As shown in Fig. 3, higher efficiency is generated by channels with a slope angle of  $10^\circ$ . However, the efficiency difference between  $10^\circ$ ,  $15^\circ$  and  $0^\circ$  is insignificant. The channel slope angle at  $20^\circ$  and  $25^\circ$  produced lower efficiency than that of  $0^\circ$ ,  $10^\circ$  and  $15^\circ$ .

#### 3.2. Discussions

From Fig. 3, the  $\eta_{max}$  obtained from the slope angles of  $0^\circ$ ,  $10^\circ$ ,  $15^\circ$  and  $20^\circ$  was between 0.55 and 0.61 with a  $U/W$  ratio of 1.15–1.58. Furthermore, the stable efficiency obtained in the  $U/W$  ratio ranged from 1 to 1.6. This condition is similar to a previous study, where efficiency was stable between 1 to 1.4 [11]. Thus, for optimal design,  $U$  should be 1.1 to 1.6 times  $W$ .

The low efficiency of  $20^\circ$  and  $25^\circ$ , when compared  $0^\circ$ ,  $10^\circ$ ,  $15^\circ$  angles, indicates that water  $EK$  increments have an influence due to slope angle increments but does not significantly affect the waterwheel's efficiency. The slope angle may have had an insignificant effect at larger angles ( $20^\circ$  and  $25^\circ$ ) due to appreciable amounts of water entering the gap between the wheel and the channel (see Fig. 4c). Water flowing between the wheel and the channel tended to increase losses and leakage. While the  $10^\circ$  and  $15^\circ$  slope channels had a water velocity

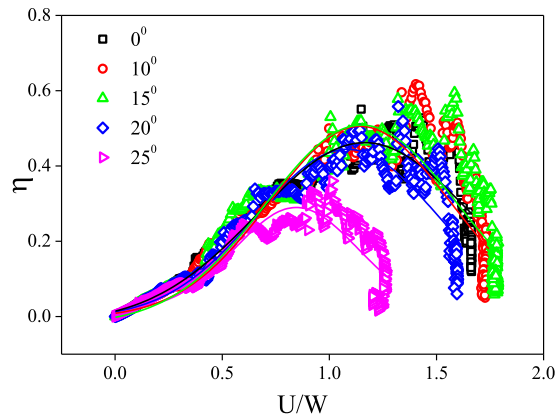


Fig. 3. Graph of relationship of  $U/W$  to efficiency ( $\eta$ ).

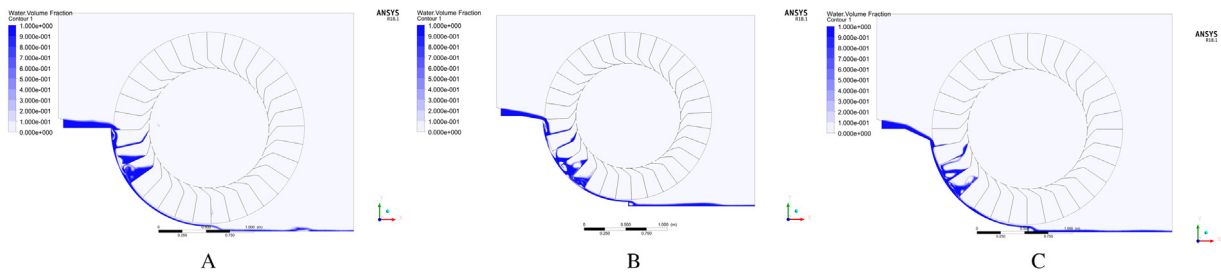


Fig. 4. Water volume fraction visualisation at optimum condition in different slope: A.  $0^\circ$ , B.  $10^\circ$ , C.  $25^\circ$ .

vector aimed directly to the bucket, they simultaneously maintained the direction of the tangential wheel, keeping the pressure received by the bucket higher than  $0^\circ$  slope channel. The high pressure received by the bucket was good for the performance of breastshot waterwheel because its increased torque, as evidenced by the water volume fraction contours in Fig. 4.

Another study on the channel slope angle of breastshot waterwheels was performed using jumping water [12]. The study's results differed from the present study's results, suggesting that jumping water could improve turbine performance [12]. This improvement would be due to the increased angle of the jumping water causing  $U$  to increase and produce greater power [12]. According to the theory of the law of mass conservation, using jumping water increases losses because the passes are increased [13]. However, the increased turbine performance based on the ratio between torque ( $\tau$ ) and  $U$  did not reach optimal conditions. When  $U$  increases, simultaneously the  $\tau$  received by the wheel decreases. However, it should be noted that the power remains dependent on  $\tau$  because the waterwheel is a type of turbine suitable for low head and large discharge.

#### 4. Conclusions

When increasing the  $EK$  of water by introducing an angle to the shape of a channel, the direction of the water velocity must be monitored. A higher slope angle channel (in this case,  $20^\circ$  and  $25^\circ$ ) can cause losses or leakage at the gap between the wheel and channel, preventing water from converting its  $EK$ , via the bucket, into mechanical power. Based on the present study's results, the optimum  $U/W$  ratio for breastshot waterwheel turbine performance is 1.1 to 1.6, which can be used as a reference for designing breastshot waterwheel turbines.

#### Acknowledgement

This work supported by the Directorate of Research and Service Community (DRPM) Universitas Indonesia with grant No: 0050/UN2.R3.1/HKP.05.00/2019.

## References

- [1] Warjito, Adanta D, Budiarmo, Prakoso AP. The effect of bucket number on breastshot waterwheel performance. In: IOP conference series: Earth and environmental science. IOP Publishing; 2018, p. 12031.
- [2] Budiarmo, Warjito, PPS JS, Prakoso AP, Adanta D. Influence of bucket shape and kinetic energy on breastshot waterwheel performance. In: 2018 4th international conference on science and technology (ICST). IEEE; 2018, p. 1–6.
- [3] Quaranta Emanuele, Revelli R. Hydraulic behavior and performance of breastshot water wheels for different numbers of blades. *J Hydraul Eng* 2016;143. 401607.
- [4] Quaranta E, Revelli R. Optimization of breastshot water wheels performance using different inflow configurations. *Renew Energy* 2016;97:243–51. <http://dx.doi.org/10.1016/j.renene.2016.05.078>.
- [5] Quaranta E, Revelli R. CFD simulations to optimize the blade design of water wheels. *Drink Water Eng Sci* 2017;10:27.
- [6] Quaranta E, Revelli R. Performance characteristics, power losses and mechanical power estimation for a breastshot water wheel. *Energy* 2015;87:315–25. <http://dx.doi.org/10.1016/j.energy.2015.04.079>.
- [7] Shabara HM, Yaakob OB, Ahmed YM, Elbatran AH. CFD simulation of water gravitation vortex pool flow for mini hydropower plants. *J Teknol* 2015;74:77–81. <http://dx.doi.org/10.11113/jt.v74.4645>.
- [8] Adanta D, Budiarmo, Warjitom, Siswantara AI. Assessment of turbulence modelling for numerical simulations into pico hydro turbine. *J Adv Res Fluid Mech Therm Sci* 2018;45:21–31.
- [9] Siswantara AI, Budiarmo, Prakoso AP, Gunadi GGR, Warjito, Adanta D. Assessment of turbulence model for cross-flow pico hydro turbine numerical simulation. *CFD Lett* 2018;10:38–48.
- [10] Helmizar H. Turbine wheel-a hydropower converter for head differences between 2.5 and 5 m. University of Southampton; 2016.
- [11] Muller G, Wolter C. The breastshot waterwheel: design and model tests. *ICE Proc-Eng Sustain* 2004;203–11.
- [12] Syafriyudin, Fajar B, Winoto SH, Facta M. Early analysis of jumping water effect on breastshot waterwheel for microhydro power plant. *J Phys Conf Ser* 2018;953:12039. <http://dx.doi.org/10.1088/1742-6596/953/1/012039>.
- [13] Munson BR, Okiishi TH, Huebsch WW, Rothmayer AP. Fluid mechanics. Wiley Singapore; 2013.