EFFECT OF THE TEST CHANNEL ON THE PERFORMANCE OF AN H-DARRIEUS HYDROKINETIC TURBINE

Christian Jair Martínez Urrutia[(a)], Isabela Florindo Pinheiro[(b)], Geraldo Lúcio Tiago Filho[(c)], Ramiro Gustavo Ramírez Camacho[(d)], Antônio Carlos Barkett Botan[(e)], Nelson Díaz Gautier[(f)]

(a) Fluminense Federal University (UFF) – Colombia – christian.m.u@outlook.com
(b) Fluminense Federal University (UFF) – Brazil – isabelaflorindo@id.uff.br
(c) Federal University of Itajubá (UNIFEI) – Brazil – gltiagofilho@gmail.com
(d) Federal University of Itajubá (UNIFEI) – Bolivia – ramirez@unifei.edu.br
(e) Federal University of Itajubá (UNIFEI) – Brazil – acbotan@yahoo.com.br
(f) Aeronautic Technologic Institute (ITA) – Venezuela – ndiazg28@gmail.com

INTRODUCTION

The current demand for more efficient and environmentally sustainable energy generation methods has driven significant improvements in alternative energy systems. One promising area is hydrokinetic energy (Yadav et al., 2023), which harnesses the kinetic energy of moving water from tides, waves, and currents in oceans, rivers, and canals (Nago et al., 2022).

Vertical-axis hydrokinetic turbines (VAHTs) are among the most notable existing technologies for harnessing hydrokinetic energy primarily due to their ability to operate without the need for flow-alignment systems, the relative ease of installing key components above water surface, among other advantages (Badrul Salleh et al., 2019; Kirke, 2020). However, these turbines require additional elements or mechanisms to enhance their performance (Shen et al., 2024). A well-known adopted technique to enhance turbine performance involves reducing the fluid pressure on the blade moving against the current. This can be achieved by placing various types of upstream deflectors to redirect the flow and minimize resistance in the drag zone (Bizhanpour et al., 2023; Chen et al., 2024; Maldar et al., 2022; R. Patel & Patel, 2022; V. K. Patel & Patel, 2021; Salleh et al., 2022; Wahyudi et al., 2015; Wu et al., 2023).

Most research on hydrokinetic turbines is based on experimental studies scaled according to the constraints of the testing channel, as well as computational fluid dynamics (CFD) simulations to optimize turbine configurations. However, performance results in many experimental studies are significantly affected by wall interference, since the ratio of the turbine diameter to channel width (D/W) is often around 0.25. Conversely, most CFD studies assume negligible wall effects by extending the distance between the turbine and domain boundaries, typically maintaining D/W ratios below 0.1 (Li et al., 2023).

Although CFD analysis provides a more adaptable and cost-effective simulation of the turbine performance and experimental tests provide essential validation through real-world data, discrepancies can arise between both approaches. In particular, numerical models may fail to accurately replicate experimental results when viscous friction in the boundary layer near the channel walls cannot be neglected, given the significant difference in the D/W ratios typically used in experiments and simulations.

Therefore, the present study investigates, through CFD analysis, the changes in the performance curve of an H-Darrieus hydrokinetic turbine (H-DHT) when channel walls are positioned sufficiently far to eliminate their influence. This study was based on the experimental work conducted by Patel et al. (2019), who demonstrated that the efficiency of an H-DHT can be improved by placing a blocking plate upstream of the drag zone. However, the results of the current analysis reveal that such performance enhancement mechanisms may not function as expected under idealized, wall-free conditions.

MATERIALS AND METHODS

This study builds upon the experimental work conducted by Patel et al. (2019), who demonstrated that the efficiency of an H-Darrieus hydrokinetic turbine (H-DHT) can be enhanced by positioning a blocking plate upstream of the drag zone. To replicate and expand on these findings under idealized conditions, a computational model was developed using the same turbine and channel configuration described in their work. The geometric specifications and dimensions used in the simulations are detailed in Table 1.

Table 1. H-DHT by Patel et al., (2019) dimensions and test channel specifications.

Parameters	Details
Blade length (l)	200 mm
Blade profile type	NACA 0018
Blade profile cord (c)	50 mm
No. of Blades (N)	3
Rotor Diameter (D)	265 mm
Solidity (σ)	18%
Width of the test channel (W)	1000 mm
Depth of water in the test channel	420 mm

The turbine was tested under the conditions shown in Table 2, and the corresponding experiment is illustrated in Figure 1.

Table 2. Input parameters from Patel et al., (2019) tests.

Parameters	Details
Flow velocity	$V = 0.389\ m/s$
Reynolds number	$Re \approx 20000$
Water density	$\rho = 998.7\ kg/m^3$
Dynamic viscosity	$\mu = 0.0001003 Pa.s$

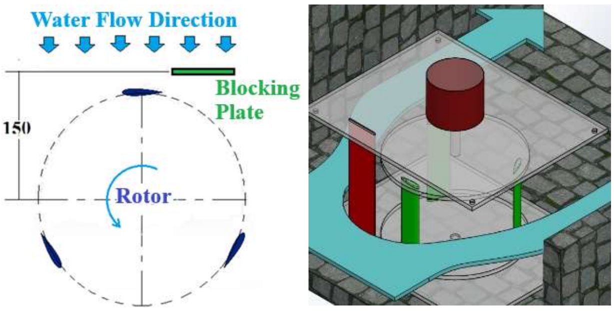

Figure 1 – Patel et al., (2019) THD-H with deflector.

Among the different configurations tested, the one featuring a 75 mm wide plate positioned 90 mm from the rotor centroid showed the best performance, increasing the maximum power coefficient from 0.125 ± 0.007 for the unblocked turbine to 0.36 with the blocking plate.

To analyze the free and blocked turbine configurations in an open space using CFD, a two-dimensional (2D) simulation was performed in ANSYS FLUENT® software. The transient k-ω SST turbulence model was used to solve the URANS equations. As shown in Figure 2, the computational domain was established with walls positioned at a distance equivalent to ten times the turbine diameter to avoid wall interference effects (Malipeddi & Chatterjee, 2012).

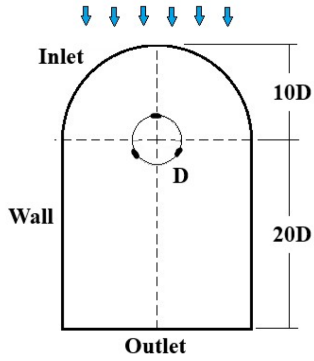

Figure 2 – Control domains in the simulations

RESULTS

Firstly, Figure 3 shows the performance curves for the H-DHT turbine in free (no blocking plate) and blocked configurations, comparing experimental and CFD results. For the free configuration ($D/W = 0.05$), the CFD simulation showed a C_P value 20.5% higher than the maximum experimental C_P ($D/W = 0.265$) at the same λ value. The numerical analysis also revealed C_P variations up to 84% across different λ values. For the turbine with the blocking plate, the simulated data indicated a maximum C_P 22.2% lower than the highest experimental value.

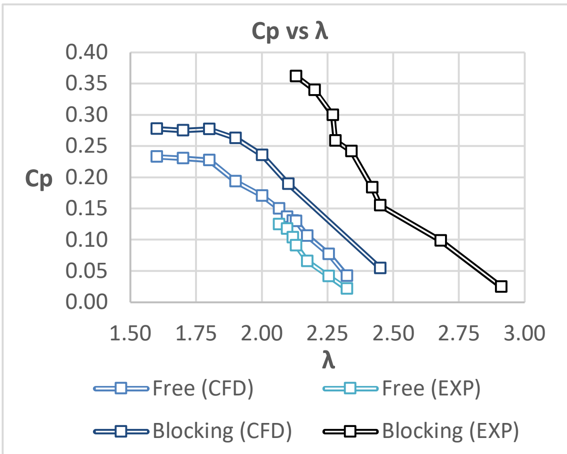

Figure 3 – Performance curves of the H-DHT obtained experimentally for rotor free □ and with blocking □ and, obtained with CFD for rotor free □ and with blocking □.

CONCLUSIONS

This study demonstrated that adding a blocking plate in a specific upstream region of the retarding zone in a Darrieus-H hydrokinetic turbine can improve its performance. However, the turbine's efficiency – for both the free and blocked configurations – also varies according to the control domain boundary distance.

H-DHT's performance improves when the counter-flow moving against the blades is diverted. Furthermore, efficiency increases when the domain walls are positioned closer to the rotor because of the continuity principle. Reducing the channel's cross-sectional area decreases vortex formation while increasing flow velocity and pressure on the turbine. Consequently, the maximum C_P value obtained experimentally was higher.

Therefore, disregarding the control domain wall distance (in this case, the test channel walls) could lead to comparisons between two fundamentally different configurations, despite some numerical similarities.

REFERENCES

Badrul Salleh, M., Kamaruddin, N. M., & Mohamed-Kassim, Z. (2019). Savonius hydrokinetic turbines for a sustainable river-based energy extraction: A review of the technology and potential applications in Malaysia. *Sustainable Energy Technologies and Assessments*, *36*, 100554. https://doi.org/10.1016/j.seta.2019.100554

Bizhanpour, A., Hasanzadeh, N., Najafi, A. F., & Magagnato, F. (2023). Investigation of different deflector geometry and mechanism effect on the performance of an in-pipe hydro Savonius turbine. *Applied Energy*, *350*, 121697. https://doi.org/10.1016/j.apenergy.2023.121697

Chen, Y., Guo, P., Lin, Y., & Li, J. (2024). Optimization and analysis of the deflector system for a bidirectional H-type hydrokinetic twin-turbine system. *Renewable Energy*, *236*, 121462. https://doi.org/10.1016/j.renene.2024.121462

Kirke, B. (2020). Hydrokinetic turbines for moderate sized rivers. *Energy for Sustainable Development*, *58*, 182–195. https://doi.org/10.1016/j.esd.2020.08.003

Li, Y., Yang, S., Feng, F., & Tagawa, K. (2023). A review on numerical simulation based on CFD technology of aerodynamic characteristics of straight-bladed vertical axis wind turbines. *Energy Reports*, *9*, 4360–4379. https://doi.org/10.1016/J.EGYR.2023.03.082

Maldar, N. R., Yee, N. C., Oguz, E., & Krishna, S. (2022). Performance investigation of a drag-based hydrokinetic turbine considering the effect of deflector, flow velocity, and blade shape. *Ocean Engineering*, *266*, 112765. https://doi.org/10.1016/j.oceaneng.2022.112765

Nago, V. G., Santos, I. F. S. dos, Gbedjinou, M. J., Mensah, J. H. R., Tiago Filho, G. L., Camacho, R. G. R., & Barros, R. M. (2022). A literature review on wake dissipation length of hydrokinetic turbines as a guide for turbine array configuration. *Ocean Engineering*, *259*, 111863. https://doi.org/10.1016/j.oceaneng.2022.111863

Patel, R., & Patel, V. (2022). Performance analysis of Savonius hydrokinetic turbine using 'C' shaped Deflector. *Https://Doi.Org/10.1080/15567036.2022.2101718*, *44*(3), 6618–6631. https://doi.org/10.1080/15567036.2022.2101718

Patel, V., Eldho, T. I., & Prabhu, S. V. (2019). Performance enhancement of a Darrieus hydrokinetic turbine with the blocking of a specific flow region for optimum use of hydropower. *Renewable Energy*, *135*, 1144–1156. https://doi.org/10.1016/j.renene.2018.12.074

Patel, V. K., & Patel, R. S. (2021). Optimization of an angle between the deflector plates and its orientation to enhance the energy efficiency of Savonius hydrokinetic turbine for dual rotor configuration. *Https://Doi.Org/10.1080/15435075.2021.1947821*, *19*(5), 476–489. https://doi.org/10.1080/15435075.2021.1947821

Salleh, M. B., Kamaruddin, N. M., & Mohamed-Kassim, Z. (2022). Experimental investigation on the effects of deflector angles on the power performance of a Savonius turbine for hydrokinetic applications in small rivers. *Energy*, *247*, 123432. https://doi.org/10.1016/j.energy.2022.123432

Shen, Z., Gong, S., Zuo, Z., Chen, Y., & Guo, W. (2024). Darrieus vertical-axis wind turbine performance enhancement approach and optimized design: A review. *Ocean Engineering*, *311*, 118965. https://doi.org/10.1016/j.oceaneng.2024.118965

Wahyudi, B., Soeparman, S., & Hoeijmakers, H. W. M. (2015). Optimization Design of Savonius Diffuser Blade with Moving Deflector for Hydrokınetıc Cross Flow Turbıne Rotor. *Energy Procedia*, *68*, 244–253. https://doi.org/10.1016/j.egypro.2015.03.253

Wu, K. T., Lo, K. H., Kao, R. C., & Hwang, S. J. (2023). Design and performance analysis of a passive rotatable deflector diversion tail for tidal current power generation hydrokinetic turbines. *Energy*, *283*, 128484. https://doi.org/10.1016/J.ENERGY.2023.128484

Yadav, P. K., Kumar, A., & Jaiswal, S. (2023). A critical review of technologies for harnessing the power from flowing water using a hydrokinetic turbine to fulfill the energy need. *Energy Reports*, *9*, 2102–2117. https://doi.org/10.1016/j.egyr.2023.01.033