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Experimental Study on Enclosed Gravitational Water Vortex Turbine (GWVT) Producing Optimum Power Output for Energy Production

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ABSTRACT

Gravitational Water Vortex Turbine (GWVT) is an emerging concept and showing its future possibility in power production by utilizing the vortex produced in its casing. GWVT performance showed comparable power efficiency and yield with conventional hydropower turbine, thus it is applicable in rural area due to its portability. This study aimed to evaluate the performance of actual physical experiment of enclosed GWVT via horizontal orientation. Conical GWVT was designed in fully enclosed system with conical turbine basin. Different flow rates (5.33 L/s, 6.01 L/s, 6.3 L/s and 6.45 L/s) were manipulated by controlling the mechanical valves and loads with 1 kg increment until the turbine was forced to stop. The optimum rpm and torque were then identified for energy production. The experimental results showed that the enclosed GWVT turbine produced at the best operating condition under flow rate of 6.3L/s with torque produced at 5.47 Nm., shaft angular velocity of 12.71 rad/s, actual power produced of 69.39W and efficiency of 16.06%. Power efficiency found in this study was comparable with the conventional GWVT turbine studies. Thus, it is feasible to operate GWVT in an enclosed casing. The result explained that the turbine worked the best at 6.3 L/s flow rate for the vortex formation to be more stable, thus harnessing more power. The results are useful as a pilot scale design prior to the actual turbine implementation in rural areas.

1. Introduction

Progress in economy of a country is highly influenced by developments in sustainable energy supply as part of their macroeconomics approach [1]. Many countries including developed and developing countries rely on fossil fuel as their sustainable energy supply, which contribute to environmental problems such as air pollution and global warming [2,3]. The availability of fossil fuel around the world remains questionable. A shift to limitless renewable energy is thus provides an alternative to produce electricity for their economical demand. From the agricultural aspects,

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renewable energy shows homogenous relationship as it is easy to merge the two subjects for operations [4]. In Malaysia, power source attribution is found to be 88.4% from fossil fuel and 11.4% from hydropower [5]. This shows that Malaysia still heavily relies on conventional fossil fuel resources as their main power source.

Issues on the lacking of rural electrification in Malaysia, especially in Sarawak and Sabah states are yet to be fully addressed. As studied via image segmentation with regional technique, it was found that 1623 locations in Sarawak had to live without electricity on the average [6]. The population of electricity coverage in Sarawak and Sabah rural areas are calculated to be at 79% compared to 99.62% in Peninsular Malaysia [7]. From the thousands of schools there, 809 are not connected to grid electricity and their power supply relies on diesel generators. Thus, lacking from grid power may persist for another ten years if not resolved immediately [8]. Sarawak has 2.77 million population and contributes to 40% of Malaysia's land, averagely 124,450 km^2 based on 2017 according to Department of Statistics Malaysia [9]. Sarawak still has 1.1 million people staying in rural areas. Based on the study by Khengwee *et al.,* [10], approximately 41,004 families did not receive electricity access for continuous 24 hours within 2014 to 2016.

Apart from that, micro hydro turbine is amongst ready technology which can provide electricity to these rural areas and caters for the hydropower generation of up to 100kW. Several sites of micro hydro-energy potential remain untapped due to the limitations of hydraulic head besides the requirement of large flow rates for the power generation. The application of conventional turbines such as Kaplan or Pelton turbines at these locations requires the design to be down-sized but more flow rate is required. To suit the volume of water entering the turbine, the design needs to be modified by providing bigger clearance for the fluid to operate efficiently and increases its fabrication cost.

Hydropower turbines falls into two major categories which are impulse turbine and reaction turbine [11]. The recent development of micro hydropower turbines is the Gravitational Water Vortex Turbine (GWVT) which provides better alternative to the conventional turbine as it is capable to extract more power compared to the conventional turbine with low hydraulic head. As the vortex flows from the radial direction, a vortex is formed and produces power from its swirl. The components of the vortex formed consist of tangential, axial and radial velocities. To date, limited actual experimental studies have been carried out on GWVT, with the earliest study was from 2013 [12]. Conventional GWVT requires free surface vortex supplied as its inlet, forcing the turbine in upright position only [13]. By enclosing the conical GWVT and substituting its inlet with penstock, the vortex flow is fully enclosed in its casing. The casing operates as the vortex's container and supports the formation of vortex [14]. By utilizing the proper design such as basin shape and overall basin configuration, a stronger vortex can be induced. Another similar operation turbine is called the Pump-as-turbine (PAT), also known as reverse-running centrifugal pump [15]. This turbine operates by water entering radially from the side of the turbine, providing swirl velocity, contacting the runner blade, before finally exiting axially using a volute casing.

Penstock inlet design offers better performance to turbine when the core requirements of inlet are met, i.e., matching nozzle design with runner type for better conversion of hydraulic head to kinetic energy [16]. This is seen from the cross-flow turbine which focusses on nozzle entry arc, allowing tangential velocity to be increased upon contacting runner blade [17]. Blade design and penstock relationship is unique for various turbine in harnessing power from water flow. Blade design configurations like blade angle and blade numbers are also crucial in influencing turbine efficiency. Some of the design configurations include the vortex angle, which found in GWVT. Study by Singh and Nestmann [18] found that blade's inlet and relative flow angle at blade's exit are inter-related. As the number of blade increases, the rotational velocity decreases which subsequently increases the axial velocity of water and ultimately reduces the turbine's efficiency [18]. Additionally, 5 numbers of blade ranging from 2 to 7 produced the highest torque due to the best clearance between blades [19]. As part of the mixed flow turbine, one of the most important parameter outputs is the tangential velocity as it converts flow to mechanical energy [20]. A runner blade produces torque via tangential force contacting upon it thus producing power through shaft rotation (rpm) [21]. As a result, torque is present as a key performance parameter in turbines [22]. During physical experiment, one of the instruments capable of measuring torque is the prony brake dynamometer system which converts the acting torque from the rotating parts to a load measuring scale at a fixed distance [23].

SOLIDWORKS® Flow Simulation is part of the Computational fluid dynamics (CFD) software which carries out fluid flow analysis [24]. The software uses Navier-Stokes equations in its solver [25]. SOLIDWORKS® Flow Simulation is able to calculate laminar and turbulent flow cases. Since turbulence flow has an inconsistent nature, SOLIDWORKS® Flow Simulation applies Favre-averaged Navier-Stokes equations which is a time-averaged analysis. By applying this method, Reynolds stresses is then added into the equations. SOLIDWORKS® Flow Simulation applies transport equations which are associated with turbulent kinetic energy and dissipation rate, known as the k-ε mode [25]. Furthermore, a study by Zarate-Orrego *et al.,* [26] proposed that numerical simulation could improve vortex flow prior to actual implementation by understanding the vortex nature. By identifying the torque generated from incoming flow's velocity, it is possible to predict the power output from the designed turbine given that the CFD analysis is setup under suitable boundary conditions [27].

In our previous study, we had simulated the turbine's optimal design parameter and determined its actual power output capacity at different flow rate using SOLIDWORKS® Flow Simulation [28]. Design parameters included enclosing the turbine casing using conical design, runner blade of 90°, and 12 numbers of blade were found to be the optimized turbine configuration. The orientation of the turbine selected was horizontal as this orientation provided better startup and reduced the torque fluctuation during turbine operation [28]. However, the actual experimental study in enclosed GWVT is still limited and yet to be established. Therefore, as continuity from our previous work, this study aimed to evaluate the performance of the actual physical experiment of enclosed GWVT via horizontal orientation in fully enclosed system with conical turbine basin to produce optimum power output for energy production.

2. Experimental Methodology

The proposed turbine design in this study followed the conical GWVT features with additional modification to its casing, based on our previous study [28]. The inlet penstock used was 2" in diameter pipe angled radially from the turbine axial axis to ensure water enters perpendicularly. The conical design was based on the ratio 0.3 diameter (0.3D) of the total diameter [29]. The additional benefits for this design are this version of modified conical GWVT, unlike the conventional GWVT which restricts the assembly to be facing upright and allows it to operate horizontally. Four flow rates i.e 5.33 L/s, 6.01 L/s, 6.3 L/s and 6.45 L/s were determined to operate the turbine as a result of opening the butterfly valve at 25°, 50°, 75° and 90°. Each flow rates were able to operate the turbine at their respective speed and torque. Thus, to identify the flow rate with the best efficiency in terms of actual power produced compared to the theoretical power, a prony brake dynamometer was introduced at the shaft which allowed the loading to be imposed. The loading started at 1 kg and increment of 1 kg was continuously added until the shaft stopped rotating. At each interval, the corresponding rpm was also recorded. The values of load and rpm allowed us to calculate the actual power output at the turbine's shaft and also to plot the performance curve.

2.1 Layout of Actual Physical Experiment

The general layout of the actual experimental setup is shown in Figure 1. The setup consisted a water tank (720 L), a submersible pump (1.5 hp), a plastic butterfly valve (4”) and the prony brake dynamometer which came with two (2) measuring scales attached to the belting around the shaft. The water was pumped at a head of 7 m throughout the experiment, allowing water flows with sufficient kinetic energy for turbine operation. The pump selected also would allow for the maximum of 9.2 L/s to ensure the turbine would never over fill as the maximum capacity was 23.3 L. Therefore, the runner blades always partially submerged. Water was discharged from the pump through a 4” pipe line but reduced to 2” upon entering the turbine by using a tapper. This allowed the water to enter at higher velocity by reducing the flow area. The 4” butterfly valve allowed the flow rate to be manipulated by controlling the gate disc opening. The water then flowed through the turbine radially to produce vortex swirl and discharged back to the water tank. At the same time, data was collected at the turbine shaft for the corresponding rpm and loadings to determine torque.

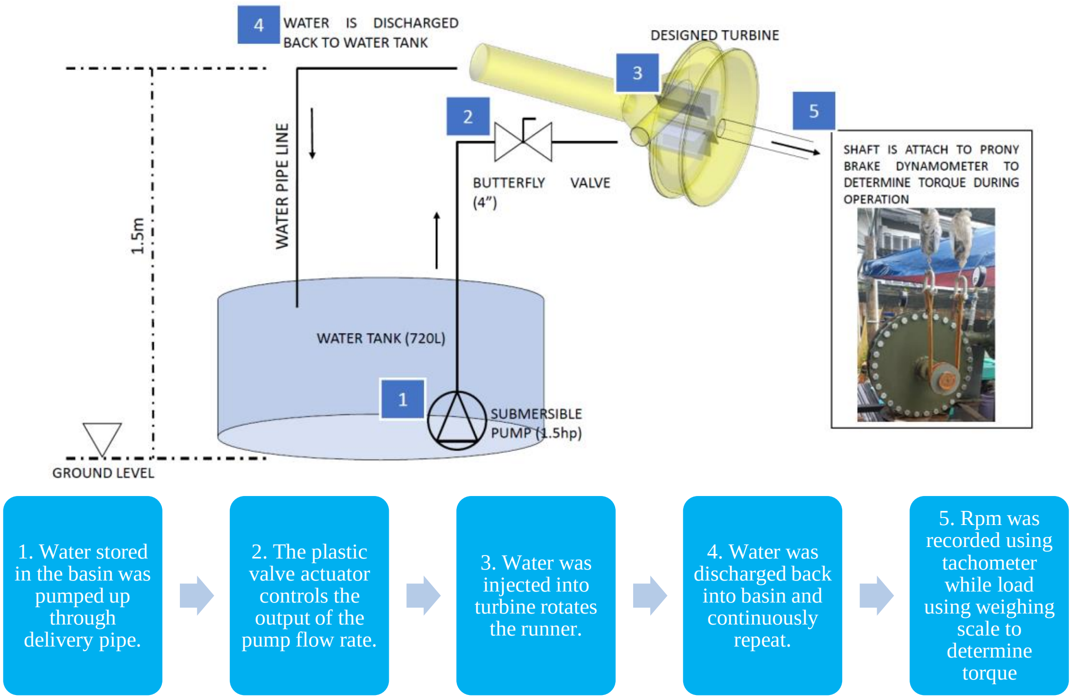


Fig. 1. General layout of actual physical experimental rig

Fig. 2. Fabricated turbine body assembled on steel structure

There were 9 main components of the turbine specification as in our previous study, as shown in Figure 3 [28]. The detailed turbine geometry design specification is stipulated in Table 1. The size and dimension setups were chosen to meet a 10 kW size turbine while being paired to a low speed permanent magnetic synchronous generator (PMG) [30].

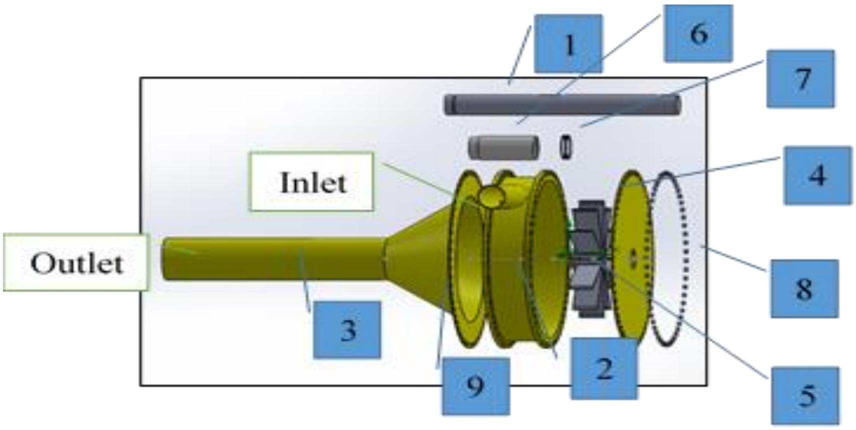


Fig. 3. Schematic diagram of enclosed GWVT labelled by numbers [28]

Table 1
Specification of turbine dimension [28]

No.	Parts	Specifications	No.	Parts	Specifications
1	Shaft	L_{shaft} = 500 mm $Ø_{shaft}$= 50 mm	6	Long Sleeve (Discharge side)	$Ø_{S1}$ = 50 mm L_{S1} = 140 mm
2	Inlet (Middle Casing)	$Ø_{inlet}$= 57 mm W = 100 mm	7	Short Sleeve (Motorside)	$Ø_{inner}$ = 50 mm L_{S2} = 10 mm
3	Draft tube (outlet)	$Ø_{outlet}$ = 100 mm	8	Bolts	$Ø_{bolt}$ = 10 mm
4	Motorside Cover	$Ø_{motor}$ = 450 mm	9	Cone Body	$Ø_{cone}$ = 330 mm
5	Runner	$Ø_{RB}$ = 280 mm			

The conical basin provides the structure for artificial vortex formation when water was introduced tangentially. The optimum vortex strength for conical basin between outer cone diameter and discharge diameter ratio of (d/D) at 30%. Any radius distance along the conical casing was determined using the following equation

$$r_{pi} = \frac{d}{2} + \left[\frac{\frac{D}{2}-\frac{d}{2}}{H_c}\right] h_{pi} \tag{1}$$

where r_{pi} and h_{pi} represents the radial distance and the corresponding length of the conical basin, respectively while d represents the discharge diameter of conical basin.

Fig. 4. Runner blade and 2” shaft mated using keyway locking system

Table 2
Runner blade specification

Item	Specification
Runner Blade diameter	280mm
Runner Blade width	250mm
Runner Blade Angle, α	90°
Number of blades, Z	12

2.2 Flow Rate Measurement

One of the methods to determine flow rate is the bucket method which relies on a bucket (known capacity) and stopwatch as its measuring tools. To improve the accuracy of this method, a large water basin was used as the container for filling. This container was able to accommodate the 0.0408 m^3/s pump running at around 10 kW of power. The water collection was repeated for each valve rounds at minimum of 3 readings and the average value was identified as the main data. As the pump used in this experiment was with known output (0.0408 m^3/s), the rough figure of pump output was estimated at each valve rounds given losses was neglected throughout the system.

2.3 Torque Measurement

A dynamometer measures torque of a rotating shaft by identifying the load produced when friction force was applied tangentially on the shaft and the distance of applied force. A proper dynamometer suitable for this is the pony brake dynamometer. The value of braking force was taken in this study which represented the amount of force imposed on a shaft at a pulley’s radius to stop its rotation. The torque from a pony brake dynamometer was calculated as below [31]

$$T = Fr \tag{2}$$

From the equation of torque, F represents net force on a pony brake and r represents drum radius. Net force was calculated by

$$F = (Load_A - Load_B) \times 9.81\ {}^{m}/_{s^2} \tag{3}$$

F represents net force, Load A represents scale A reading, Load B represents scale B reading.

2.4 Rpm Measurement

The instrument to measure rotations in shaft is called a tachometer. A tachometer displays a shaft rotation speed either by a calibrated analogue dial or digital display. A tachometer has a diversity of operating method based on suitability of working condition. This experiment used the handheld direct contact tachometer where the rubber tip of tachometer was placed on the shaft throughout the measuring time. For this study, the tachometer was maintained for 60 seconds for each turbine settings. The value of shaft speed was substituted into the equation below to determine the angular velocity

$$\omega = \frac{2\pi N}{60} \tag{4}$$

From the equation above, ω represents angular velocity and N represents shaft's rpm (rotation speed).

2.5 Turbine Actual Power

$$P_{actual} = T\omega \tag{5}$$

From the equation above, P is the power produced by shaft, T represents torque while ω is angular velocity. The general formula of potential power ($P_{potential}$) in a fluid is given by

$$P_{potential} = \rho g Q h \tag{6}$$

where ρ is density of water (kg/m^3), g is gravity (m/s^2), Q is flow rate (m^3/s) and h is net head (m). The available power in a given flow is mainly affected by volume flow rate and available net head. The equation also gives us a general insight for turbine selection. For example, after identifying the head available was high we usually employed impulse turbine to suit the turbine site requirement, as well as the available power from the site to size our turbine. The efficiency of the turbine was then calculated as below

$$\eta_{turbine} = \frac{P_{actual}}{P_{potential}} \times 100\% \tag{7}$$

where $\eta_{turbine}$ represents performance of the turbine. During the experiment, the efficiency of the turbine would be mainly viewed at 2 perspectives which were the best efficiency point during load application and the different flow rate while keeping head constant. Since the flow rate was controlled by a valve, we could identify the efficiency produced at each increment of flow rate.

The performance curve of a turbine exhibited a lot of key parameters such as RPM, Torque, Power and Efficiency, and these data were viewed together in a multiple graph plot [32]. Usually, the performance curve of a turbine follows a quadratic shape with a maximum point on top indicating the best efficiency point. The performance curve of model tests was required to estimate the parameters produced by the actual turbine later. During practical implementation, the performance curve provides important parameters such as output and efficiency. The turbines to be implemented on the site can further be identified by numbers and sizes too, which ultimately account to economic feasibility [33]. This is usually the main factor in project development to estimate the time needed to regain project investment cost.

3. Results and Discussion

3.1 Flow Rate Results

The performance of the turbine under actual turbine experiment was tested at four valve openings (using a 4" plastic valve) which consisted of fully opened, three-quarter opened, half opened and quarter opened. After turning on the pump, a gradual load of 1kg was imposed on the turbine until the shaft was fully stopped. The rpm of the shaft was measured for each load imposed. Time taken for the pump to fill 100L of water was taken by diverting the discharge pipe to another tank. The time taken was repeated three times for each valve openings. The values were then average out. Table 3 below shows the recorded time taken for each valve openings and their respective flow rate:

Table 3
Respective flow rate measured at different valve openings

Valve Opening	25°	50°	75°	90°
Time taken 1,s	20.97	20.06	18.04	15.3
Time taken 2,s	17.6	14.68	16.03	16.34
Time taken 3,s	17.78	15.18	13.59	14.94
Average	18.79	16.64	15.89	15.53
Flow rate (L/s)	5.33	6.01	6.3	6.45

3.2 Torque Results

In this experiment, the measuring scale allowed us to increase 1 kg by 1 kg as the sensitivity of the main scale is only 1 kg and ended up at 200 kg [22]. The frictional force opposed the counter clockwise motion of the shaft. As the rotating shaft was subjected to the tensional load of a belting system, the load produced on the tugging side of the belt (left side) was higher compared to load produced on the aligned with the counter clockwise motion (right side). Thus, the left belting was labelled as scale A while the right belting was named scale B. Based on the experimental data collection, scale B produced roughly quarter of the load from scale A. The maximum load found at scale A was 12 kg while scale B produced 4 kg concurrently. The maximum load here referred to the load subjected to the shaft to completely stop rotating (0 rpm).

From the data extracted in Table 3, we could define that the maximum torque could not be the criteria for power production but only as a standard limit the turbine could handle load, thus the shaft would also stop rotating. Rated torque provides a balance with sufficient rpm to allow power to be produced [32]. Based on Table 4, 90° and 50° valve openings produced the highest torque at 7.95 N.m. Nonetheless, in predicting the optimum setting for the turbine, the estimation was based on rated torque. Rated torque refers to the balance combination of torque and rpm which produced the highest power for the respective inlet flow rate.

Table 4
Rated torque and maximum torque produced at varying flow rates

Valve Opening	Rated Torque (N.m.)	Rated (rpm)	Power (Watt)	Maximum Torque (N.m.)
25°	3.98	73.67	30.64	4.47
50°	5.96	104.67	65.30	7.95
75°	5.47	121.33	69.39	6.95
90°	5.47	116.33	66.53	7.95

The powers produced from the 90° and 50° valve openings were also very similar at 65.30W and 66.53W which the differences came from the rpm of the shaft. However, the torque produced at 75° valve opening was lower (6.95 N.m.) than the two mentioned previously. Although lower maximum torque was produced, 75° valve opening produced the highest power (69.39W).

3.3 Turbine's Shaft Rpm Results

The rated torque was able to be identified through maximum power output as a product to the combination of rated torque and rated rpm. The highest rated rpm produced was at 121.33 based on Table 4. The result was from 75° valve opening at flow rate of 0.00629 m^3/s. However, the rated rpm dropped to 116.33 for full valve opening at flow rate of 0.00645 m^3/s. In comparison to conventional GWVT setting, study by Dhakal *et al.,* [34] found that the cylindrical basin rpm sometimes drops to below 50 as a result of the design that is constantly exposed to the atmospheric air [34]. It requires high precision in the inlet of the turbine to obtain a stable vortex with high vortex strength enough to contribute to higher rpm (above 100). Nonetheless, the study shifted to conical basin and found that the rpm drastically improved to 101.8 rpm and 127 rpm. This proved that using conical basin setup contributes to vortex formation and improves the circulation (vortex strength), eventually producing higher rpm when a runner blade is present.

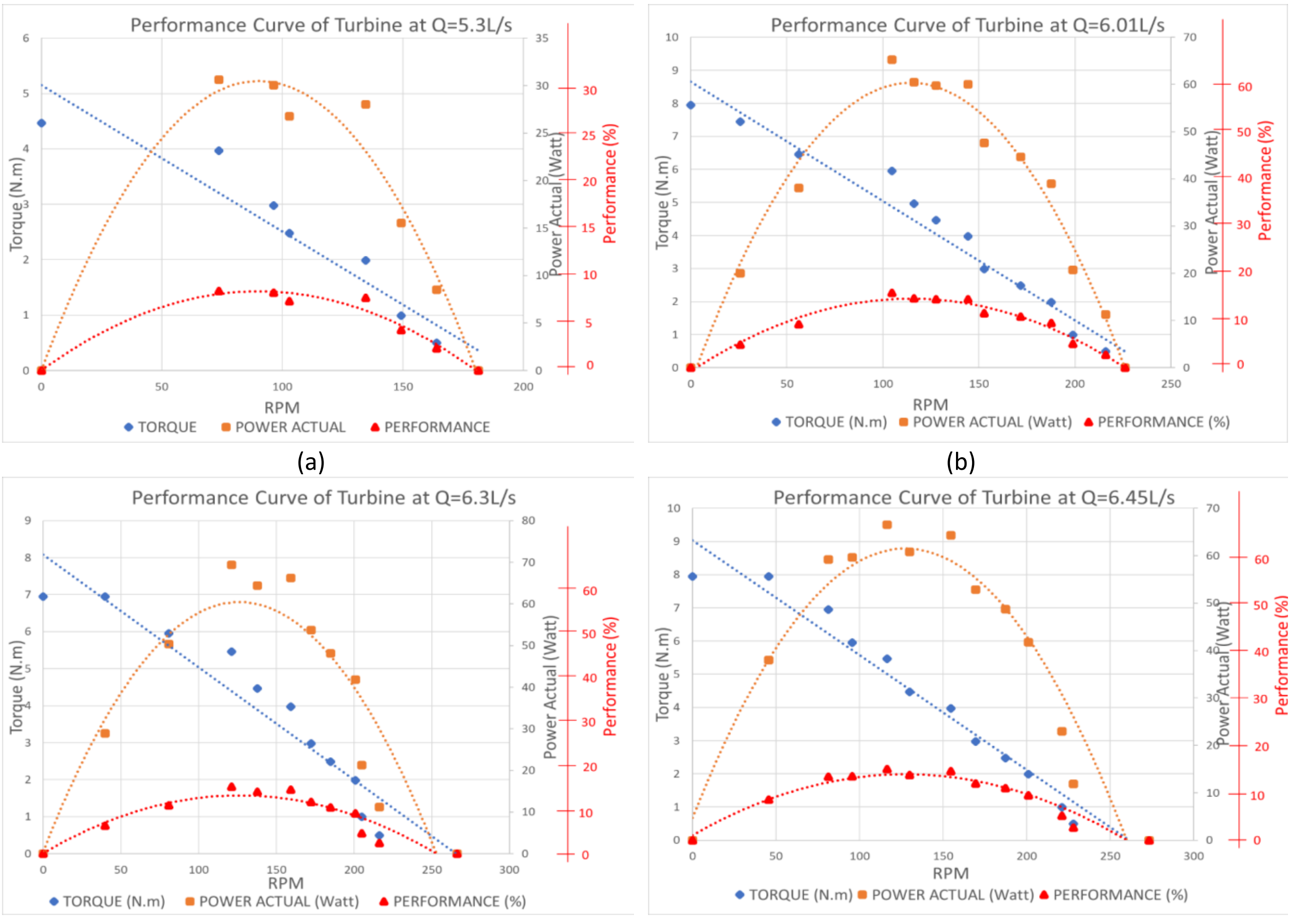
3.4 Performance Curve of Turbine at Different Flowrate

Potential power was calculated using Eq. (6) to calculate the corresponding performance using Eq. (7). Based on Table 5, the performance curve of the enclosed GWVT was able to be constructed with the sufficient data computed. The performance curve relationships between rpm and torque, power and efficiency at different flow rates developed are shown in Figure 5.

Table 5
Performance of turbine at various flow rate

Valve opening (°)	25	50	75	90
Flow Rate (L/s)	5.33	6.01	6.30	6.45
Torque (Nm)	3.98	5.96	5.47	5.47
Avg RPM	73.67	104.67	121.34	116.34
Ang. Vel. (rad/s)	7.72	10.97	12.71	12.19
Power actual (W)	30.64	65.3	69.39	66.53
Potential Power (W)	365.6	412.69	432.25	442.28
Performance (%)	8.39	15.83	16.06	15.05

Based on Figure 5, the performance curve followed a parabolic shape with the peak of the curve representing the best operating region of the flow rate in operation. The highest power and performance were found for flow rate at 6.3 L/s with 69.39 Watt and 16.06 % performance, respectively. The flow rate showed high suitability towards the turbine design in comparison to the fully opened valve with the performance dropped a bit by roughly 1%. This justified that the inlet penstock played a major role in determining the rpm output. In a study by Adhikari and Wood [16], it was a core requirement to match the inlet nozzle with the runner design to maximize energy conversion of head to kinetic energy as it contributes to higher efficiency output. Thus, at a flow rate of 0.00629 m^3/s, the penstock was able to produce stronger vortex for the turbine as the responding rated rpm was the highest. Even though the pump output head was at a constant 7 m throughout the study (neglecting any losses in pipe bends), higher velocity was recorded throughout the inlet pipe prior to turbine casing entry. Even though the pump output head was at a constant 7 m throughout the study, it was found that the velocity of the water in the pipe before entering turbine casing kept increasing as volume flow rate increased due to the opening valve setting. Higher velocities induced the turbulence flow which provided head losses and this could be calculated using the Moody Chart diagram in response to pipe length and roughness.



(a) (b) (c) (d)

Fig. 5. Performance curve relationships between rpm and torque, power and efficiency at different flow rates; (a) Q= 5.3L/s, (b) Q=6.01 L/s, (c) Q=6.3L/s, (d) Q=6.45L/s

The calculation of internal volume for the turbine was 0.0233m^3. The calculation was made with the aid of computer software. The flow rate that produced the highest efficiency was 0.00629m^3/s which was about 27% of the total turbine volume while the flow rate that produced the lowest efficiency was 0.00533 m^3/s which was about 22.8%. This result showed that the turbine flow was always partially submerged during operations. It is important to understand that the turbine must be partially submerged to produce the highest possible efficiency. A study by Bajracharya *et al.,* [35] in 2012 indicated that the runner blades were not fully submerged in the rotating fluid where only the top inner edges were the main contact point to the runner blade as the water dipped around the vortex centre [35]. Thus, it is important that the flow rate does not over fill the capacity of the turbine as it may cause the turbine to be flooded and pressurized. Over filled flow rate will reduce the efficiency of operations as the formation of vortex will be disrupted. Thus, the comparison with other studies as shown in Table 6 indicated that the performance of GWVT in this study is comparable with other studies. Moreover, the actual physical experimental in this study showed high efficiency in terms of force and torque compared to the simulated one as higher rpm and power were harnessed (Table 7).

Table 6
Comparison study on the performance of conventional GWVT

No.	Efficiency of Open/ FSV GWVT	Reference(s)
1	15.1 %	Mulligan and Hull [37]
2	27.74 %	Dhakal *et al.,* [34]
3	15.1 %	Power *et al.,* [12]
4	16.06 %	This study

Table 7
Comparison study between simulation and actual enclosed GWVT using conical design

Parameter	Simulation [28]	This study
Force (N)	15.31	47.56
Torque (Nm.)	1.76	5.47
RPM	-	121.34
Power (Watt)	-	69.39
Performance (%)	-	16.06

4. Conclusion

The experimental study on GWVT aimed to produce optimum power output for energy production has been successfully carried out. A maximum of 16.06% efficiency performance was achieved at 6.3 L/s flowrate with torque, shaft angular velocity and actual power produced were 5.47 Nm., 12.71 rad/s, and 69.39 W respectively, using an enclosed system. The efficiency was comparable to other conventional GWVT studies. Nonetheless, this study emphasized the feasibility of running the turbine horizontally and within an enclosed domain to produce vortex that is able to be extracted for power generation. Too much flow would endanger the turbine as the pressure will be increasing thus affecting the fittings while too low flow rate will cause the turbine to underperformed. Thus, the turbine works best under partial submergence as there is sufficient space for vortex core to be produced providing more stable vortex for energy harnessing. The data is crucial to control the volume flow rate at implementation sites using valves to maintain high efficiency of power production and safety of the pump for long term usage. The design and operational procedure in this study can be used and applied in rural areas to produce electricity with small population but give significant impact to the community.

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References
[1] Azam, Muhammad. "Energy and economic growth in developing Asian economies." *Journal of the Asia Pacific Economy* 25, no. 3 (2020): 447-471. https://doi.org/10.1080/13547860.2019.1665328
[2] Sugiawan, Yogi, and Shunsuke Managi. "New evidence of energy-growth nexus from inclusive wealth." *Renewable and Sustainable Energy Reviews* 103 (2019): 40-48. https://doi.org/10.1016/j.rser.2018.12.044
[3] Martins, Florinda, Carlos Felgueiras, Miroslava Smitkova, and Nídia Caetano. "Analysis of fossil fuel energy consumption and environmental impacts in European countries." *Energies* 12, no. 6 (2019): 964. https://doi.org/10.3390/en12060964
[4] Mondal, Mithun, Djamal Hissein Didane, Alhadj Hisseine Issaka Ali, and Bukhari Manshoor. "Wind Energy Assessment as a Source of Power Generation in Bangladesh." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 26, no. 3 (2022): 16-22. https://doi.org/10.37934/araset.26.3.1622
[5] Haiges, Rina, Y. D. Wang, A. Ghoshray, and A. P. Roskilly. "Optimization of Malaysia's power generation mix to meet the electricity demand by 2050." *Energy Procedia* 142 (2017): 2844-2851.

https://doi.org/10.1016/j.egypro.2017.12.431

[6] Khamis, Aziah, Tamer Khatib, Nur Amira Haziqah Mohd Yosliza, and Aimie Nazmin Azmi. "Optimal selection of renewable energy installation site in remote areas using segmentation and regional technique: A case study of Sarawak, Malaysia." *Sustainable Energy Technologies and Assessments* 42 (2020): 100858. https://doi.org/10.1016/j.seta.2020.100858

[7] Borhanazad, Hanieh, Saad Mekhilef, R. Saidur, and G. Boroumandjazi. "Potential application of renewable energy for rural electrification in Malaysia." *Renewable Energy* 59 (2013): 210-219. https://doi.org/10.1016/j.renene.2013.03.039

[8] Mahmud, Abdul Muhaimin. "Evaluation of the Solar Hybrid System for Rural Schools in Sabah; Malaysia." In *World Renewable Energy Congress-Sweden*; 8-13 May; 2011; Linköping; Sweden, no. 57, pp. 2977-2984. Linköping University Electronic Press, 2011. https://doi.org/10.3384/ecp110572977

[9] Malaysia, D. O. S. "Department of Statistics Malaysia, Official Portal - Sarawak." *Department of Statistics Malaysia Official Portal, The Source of Malaysia's Official Statistics*. Accessed April 6, 2020. https://www.dosm.gov.my/v1/index.php?r=column/cone&menu_id=clJnWTlTbWFHdmUwbmtSTE1EQStFZz09#.

[10] Khengwee, Tan, P. R. P. Hoole, K. Pirapaharan, Norhuzaimin Julai, Al-Khalid Hj Othman, Martin Anyi, Ahmed MA Haidar, and S. R. H. Hoole. "A review of sarawak off-grid renewable energy potential and challenges." *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)* 9, no. 3-10 (2017): 29-33.

[11] Elbatran, A. H., O. B. Yaakob, Yasser M. Ahmed, and H. M. Shabara. "Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review." *Renewable and Sustainable Energy Reviews* 43 (2015): 40-50. https://doi.org/10.1016/j.rser.2014.11.045

[12] Power, Christine, Aonghus McNabola, and Paul Coughlan. "A parametric experimental investigation of the operating conditions of gravitational vortex hydropower (GVHP)." *Journal of Clean Energy Technologies* 4, no. 2 (2016): 112-119. https://doi.org/10.7763/JOCET.2016.V4.263

[13] Yaakob, O. B., Yasser M. Ahmed, A. H. Elbatran, and H. M. Shabara. "A review on micro hydro gravitational vortex power and turbine systems." *Jurnal Teknologi* 69, no. 7 (2014): 1-7. https://doi.org/10.11113/jt.v69.3259

[14] Sreerag, S. R., C. K. Raveendran, and B. S. Jinshah. "Effect of outlet diameter on the performance of gravitational vortex turbine with conical basin." *International Journal of Scientific & Engineering Research* 7, no. 4 (2016): 457-463.

[15] Frosina, Emma, Dario Buono, and Adolfo Senatore. "A performance prediction method for pumps as turbines (PAT) using a computational fluid dynamics (CFD) modeling approach." *Energies* 10, no. 1 (2017): 103. https://doi.org/10.3390/en10010103

[16] Adhikari, Ram, and David Wood. "The design of high efficiency crossflow hydro turbines: A review and extension." *Energies* 11, no. 2 (2018): 267. https://doi.org/10.3390/en11020267

[17] Khosrowpanah, Shahram, A. A. Fiuzat, and Maurice L. Albertson. "Experimental study of cross-flow turbine." *Journal of Hydraulic Engineering* 114, no. 3 (1988): 299-314. https://doi.org/10.1061/(ASCE)0733-9429(1988)114:3(299)

[18] Singh, Punit, and Franz Nestmann. "Experimental investigation of the influence of blade height and blade number on the performance of low head axial flow turbines." *Renewable Energy* 36, no. 1 (2011): 272-281. https://doi.org/10.1016/j.renene.2010.06.033

[19] Sritram, P., and R. Suntivarakorn. "The effects of blade number and turbine baffle plates on the efficiency of free-vortex water turbines." In *IOP Conference Series: Earth and Environmental Science*, vol. 257, no. 1, p. 012040. IOP Publishing, 2019. https://doi.org/10.1088/1755-1315/257/1/012040

[20] Breeze, Paul. *Hydropower*. Academic Press, 2018. https://doi.org/10.1016/B978-0-12-812906-7.00006-5

[21] Teresa, T., G. G. Visal, P. Sai Ram, and M. Srimani Kumar. "Experimental analysis on Francis turbine at full load to determine the performance characteristics curves." *International Journal of Mechanical Engineering and Technology* 9, no. 2 (2018): 663-669.

[22] Ullah, Rizwan, Taqi Ahmad Cheema, Abdul Samad Saleem, Sarvat Mushtaq Ahmad, Javed Ahmad Chattha, and Cheol Woo Park. "Preliminary experimental study on multi-stage gravitational water vortex turbine in a conical basin." *Renewable Energy* 145 (2020): 2516-2529. https://doi.org/10.1016/j.renene.2019.07.128

[23] Sewucipto, Sanjaya, and Triyogi Yuwono. "The Influence of Upstream Installation of D-53° Type Cylinder on the Performance of Savonius Turbine." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 3, no. 1 (2021): 36-47.

[24] Versteeg, Henk Kaarle, and Weeratunge Malalasekera. *An introduction to computational fluid dynamics: the finite volume method*. Pearson Education, 2007.

[25] Sobachkin, A., and G. Dumnov. "Numerical basis of CAD-embedded CFD." In *NAFEMS World Congress*, vol. 2013, pp. 1-20. 2013.

[26] Zarate-Orrego, Sergio Antonio, Gerardo Andrés Torres-Casierra, and Efraín Baldemar del Risco-Moreno. "Horizontal

vortex single chamber hydroturbine." *Revista Facultad de Ingeniería Universidad de Antioquia* 79 (2016): 150-162. https://doi.org/10.17533/udea.redin.n79a14

[27] Elsayed, Ahmed M. "Design Optimization of Diffuser Augmented Wind Turbine." *CFD Letters* 13, no. 8 (2021): 45-59. https://doi.org/10.37934/cfdl.13.8.4559

[28] Aziz, Muhammad Qamaran Abdul, Juferi Idris, and Muhammad Firdaus Abdullah. "Simulation of the Conical Gravitational Water Vortex Turbine (GWVT) Design in Producing Optimum Force for Energy Production." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 89, no. 2 (2022): 99-113. https://doi.org/10.37934/arfmts.89.2.99113

[29] Sreerag, S. R., C. K. Raveendran, and B. S. Jinshah. "Effect of outlet diameter on the performance of gravitational vortex turbine with conical basin." *International Journal of Scientific & Engineering Research* 7, no. 4 (2016): 457-463.

[30] Ebhota, Williams S., and Freddie Inambao. "Design basics of a small hydro turbine plant for capacity building in sub-Saharan Africa." *African Journal of Science, Technology, Innovation and Development* 8, no. 1 (2016): 111-120. https://doi.org/10.1080/20421338.2015.1128039

[31] Nuramal, Agus, Putra Bismantolo, Abhijit Date, Aliakbar Akbarzadeh, Afdhal Kurniawan Mainil, and Ahmad Fauzan Suryono. "Experimental study of screw turbine performance based on different angle of inclination." *Energy Procedia* 110 (2017): 8-13. https://doi.org/10.1016/j.egypro.2017.03.094

[32] Ullah, Rizwan, Taqi Ahmad Cheema, Abdul Samad Saleem, Sarvat Mushtaq Ahmad, Javed Ahmad Chattha, and Cheol Woo Park. "Performance analysis of multi-stage gravitational water vortex turbine." *Energy Conversion and Management* 198 (2019): 111788. https://doi.org/10.1016/j.enconman.2019.111788

[33] Thapar, O. D. "Chapter 5 - Modern Hydroelectric Engg Practice." *Modern Hydroelectric Engineering Practice in India: Electro-Mechanical Works - Volume 1* (2020).

[34] Dhakal, Subash, Susan Nakarmi, Pikam Pun, Arun Bikram Thapa, and Tri Ratna Bajracharya. "Development and testing of runner and conical basin for gravitational water vortex power plant." *Journal of the Institute of Engineering* 10, no. 1 (2014): 140-148. https://doi.org/10.3126/jie.v10i1.10895

[35] Bajracharya, Tri Ratna, Shree Raj Shakya, Ashesh Babu Timilsina, Jhalak Dhakal, Subash Neupane, Ankit Gautam, and Anil Sapkota. "Effects of geometrical parameters in gravitational water vortex turbines with conical basin." *Journal of Renewable Energy* 2020 (2020). https://doi.org/10.1155/2020/5373784

[36] Adhikari, Pradhumna, Umesh Budhathoki, Shiva Raj Timilsina, Saurav Manandhar, and Tri Ratna Bajracharya. "A study on developing pico propeller turbine for low head micro hydropower plants in Nepal." *Journal of the Institute of Engineering* 9, no. 1 (2013): 36-53. https://doi.org/10.3126/jie.v9i1.10669

[37] Mulligan, S., and P. Hull. "Design and Optimisation of a Water Vortex Hydropower Plant." *IT Sligo Research*, 2010.