Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.14744/thermal.0000897

Research Article

Effect of the design variables on the vortex water turbine performance

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ARTICLE INFO

Article history
Received: 19 July 2024
Revised: 19 October 2024
Accepted: 22 October 2024

Keywords:
Experimental; Performance; Water Vortex; Water Vortex Power Plant

ABSTRACT

The water vortex power plant has become of more interest to researchers due to its important role in renewable energy technologies, allowing it to operate with low heads and flow rates. The novelty of the work compared to previous efforts is that a group of variables studied together that have an important role in increasing the efficiency of the system, such as the increase and decrease in the number of blades, the effect of weight through changing the type of metal, and the height of the turbine from the bottom of the basin. Therefore, this article evaluated the performance of the water vortex plant, in which several variables were studied: the number of turbine blades, turbine weight, and turbine height from the basin floor where the water vortex system was designed and tested by using four turbines: one of them had six blades and another four blade are made from carbon steel alloy and two other turbines, which one of them six blades the other four blades are made of galvanized alloy. Practical tests also concluded that the four-blade turbine, made of carbon steel alloy, achieved an efficiency of up to 69%. The weight of the turbine plays a vital role in determining the system efficiency when a six-blade turbine made of carbon alloy with a higher weight and a height of 3 cm reaches 64% as the maximum efficiency. Also, the experiments found that the highest efficiency reaches the turbine at a height of 3 cm from the bottom of the basin after different heights were chosen for the turbines used from the bottom, which included (1.5 cm, 3 cm, 5 cm, 8 cm).

Cite this article as: Zainal HM, Ahmed OK. Effect of the design variables on the vortex water turbine performance. J Ther Eng 2025;11(2):314–330.

INTRODUCTION

Nowadays, the world is witnessing a significant increase in the population and a greater need for energy resources, as well as a huge increase in manufacturing processes, so energy production, especially electric energy, is required. Therefore, the use of fossil fuels to generate most of the energy is one of the main causes of environmental pollution, greenhouse gas emissions, and global warming. Therefore, it is necessary to search for modern and universally usable energy to solve this challenge [1]. Researchers around the world are creating technologies to help transition to renewable sources of low-carbon energy generation, and it has been proven that all new renewable energy technologies are characterized by a number of characteristics, including abundant, environmentally friendly, and promising. Hydroelectric power is one of the renewable energy sources. Therefore, the development and improvement of

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This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkılıç

Published by Yıldız Technical University Press, İstanbul, Turkey

electricity generation using water is a strategic and fundamental task [2]. Conventional hydropower is characterized by its environmental and economic disadvantages, such as huge dams, in terms of high costs of civil works, large area covered, high operating and maintenance costs, and high water or flow. To overcome this problem, Gravitational Water Vortex Power Plants (GWVPP) are popular due to their simple design and installation [3].

The hydro vortex power plant is a solution to the problems caused by the increased demand and distribution of electricity resulting from increased economic growth because it is easy to manufacture and use [4]. It is one of the important ways to respond to the growing demand for electricity through the construction of small and medium-sized hydroelectric power plants, which are one of the renewable energy sources [5]. This fact is well known, but there are many challenges in the use of hydropower, where small turbine units are used commensurate with the method of water movement to convert part of the hydropower into electricity and to extract energy from water. There are two main methods used, the most important of which is the potential energy of water and pressure energy, which is done by storing water in reservoirs. The kinetic energy of the flowing fluid has a direct role in the generation of electricity [6]. The Gravitational Water Vortex Power Plant is classified as a small hydroelectric power plant due to its reported maximal power generation not surpassing 100 kilowatts. One notable benefit of employing this method is its ecological friendliness and minimal head requirement, ranging from 0.7 to 3 m [7]. Creating a water vortex, where an installed turbine collects rotational energy and converts it through the shaft to the electric generator [8, 9]. Gravitational vortex water turbines work similarly to impulse turbines. The water is transferred to a circular basin. The shape of the basin has a role in creating a water vortex, where an installed turbine collects rotational energy and converts it through the shaft to the electric generator [9]. To enhance the operational efficiency of water turbines, it is necessary to conduct a comprehensive analysis of the flow field for what has an important and effective role [10]. Air core is an important factor for generating a strong vortex and is one of the main reasons for improving the efficiency of the station [11]. Conducted an analytical study of a wide range of Basin design configurations by applying computational fluid dynamics methodology. It turns out that the optimal configuration for the production of a water spiral is a cylindrical through. The design of the hydro vortex power plant tool (GWVPP) certainly requires a number of effects that play an important role in the occurrence of a vortex, including the height of the turbine and the water discharge hole, where the highest results were obtained with a discharge outlet of 5 cm at 3.46 W at a turbine height of 22 cm, while the results obtained with a discharge outlet of 6 cm in a basin produced 2.51 W at a turbine height of 28 cm [12]. Cheema et al. [13] studied the performance of the two-stage gravity water vortex turbine (GWVT) used inside a cone-shaped basin. The increase in performance parameters resulting from feeding the lower stages shows an additional effect on the stage located above it due to the generation of a forced vortex near the upper stage. Dahal et al. [14] resulted in a 3.84 Watt increase in power generation in the miniature model when a booster runner was added, accounting for 20.4% of the main runner's 63.55% efficiency. The efficiency of gravity vortex turbines has been the subject of much research [15]. The Gravitational Water Vortex power plant system technology is still being developed. Thus, researchers create the runner by adjusting the tip diameter-to-axis ratio, blade position, size, number, etc. Fewer blades increase efficiency, whereas increasing blade radius decreases it [16]. Kim et al. [17] conducted the effect of the number of blades of vortex turbines tested using turbines with 5, 6, 8, and 10 blades. Finally, the eight-blade turbine reached an efficiency of 57% with the fixed Vortex Air Core. Sharif et al. [18] carried out a comprehensive numerical analysis of five different types of runners (Fig. 1). Experimental consideration was taken of three runners with the highest water pressure applied to the Blades. The efficiency of the round curved runner's sewer was 48.02 %. In comparison, the efficiency of the J-shaped conical sewer was 42.17 %, and the efficiency of the spiral runner's sewer was 38.64 %. The runner height is the most important factor to consider when designing the GWVPP turbocharger, especially when using a cone-shaped trough, according to the results of performance tests conducted on a group of runners [19]. Dhakal et al. [20] aim to strengthen the runner to improve the efficiency of GWVPP. Three runner designs with straight, twisted and curved sections undergo Computational Fluid Dynamics (CFD) examination. CFD research revealed that the curved blade configuration shows the highest level of efficiency, reaching a maximum efficiency of 82%. By comparison, the straight blade configuration achieved 46% efficiency, while the twisted blade configuration achieved 63% efficiency. The number of blades, blade angle, runner speed, as well as blade profile are important parameters affecting the efficiency of GWVPP [21]. Through a review of previous articles, it became clear that no article explains the combined effect of the number of blades and the type of alloy used in the manufacture of turbine blades; in other words, the weight of the turbine and the height of the turbine on the performance of the system in a comprehensive manner and explained.

The main objective of the current work and its novelty represented with study the effect of a group of variables together was studied, which have an important role in increasing the efficiency of the system, such as the number of blades by increasing to 6 blades and decreasing to 4 blades, as well as the effect of weight by changing the type of manufacturing metal, where the first group was manufactured from carbon steel alloy (S5 A105 Gr 1042) and the other group from galvanized alloy, as well as the height of the turbine from the bottom of the basin.

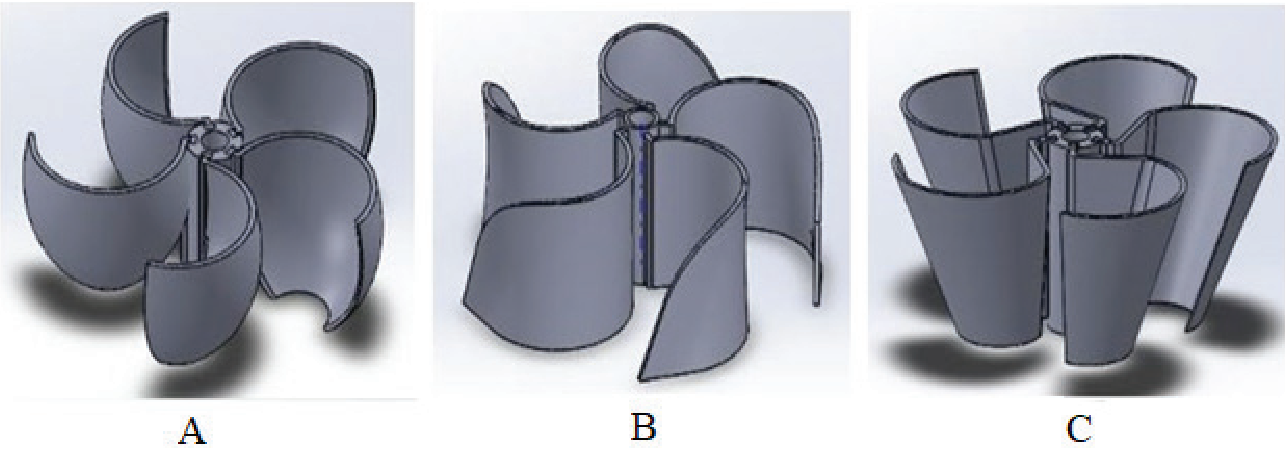


Figure 1. (A) round curved runners, (B) helical runners, (C) J-shaped conical.

MATERIALS AND METHODS

Through our study of a group of previous research that is directly related to water vortex, it turns out that there are a set of design variables that need to be studied together, which includes the number of turbine blades, where the effective area of the turbine increases by increasing the number of blades, as well as the weight of the turbine and also the height of the turbine from the bottom of the basin to find a suitable location where the turbine achieves the highest efficiency as shown in Figure 2. The design of the turbine is one of the main parameters that have an effective role in determining the efficiency of the gravity water vortex power plant because of its main role in exploiting and absorbing the maximum amount of water energy generated due to the vortex and drainage hole at the bottom of the basin plays an important role in developing a strong vortex. It has led us to focus more on the design of the turbine, as this research aims to modify, analyze, and improve the performance of the water vortex power plant through a change in the number of blades, the weight of the turbine, and the height of the turbine from the bottom of the basin. The article was arranged as follows: the practical side and the parts of the device were explained in the third section. The mathematical equations were presented in the fourth section. Discussion of the results was described in the fifth section, and the conclusions were presented in the sixth section.

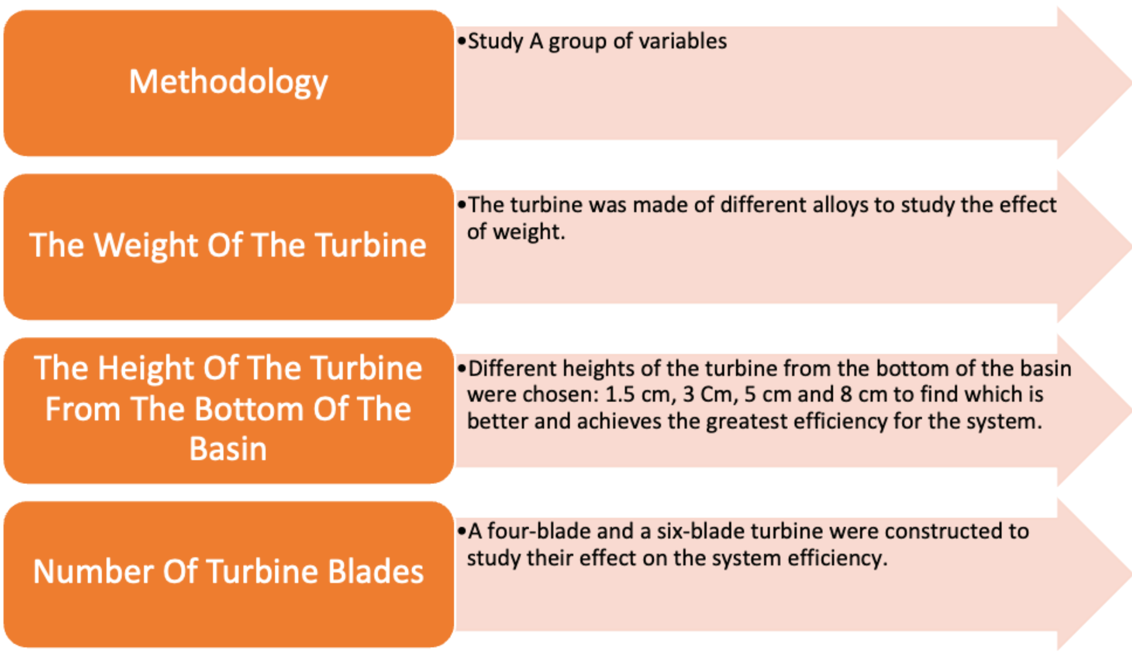


Figure 2. All variables studied in this work.

Experimental Side

To analyze the performance of the gravitational water vortex power plant (GWVPP) through an adjustment in the number of blades and the material from which the turbine is made, Where the GWVPP developer project was installed in the building Technical Engineering College - Kirkuk was used. Figure 3 shows the system's dimensions for design purposes.

The experimental facility consists of the following parts (Fig. 4, 5):

- Overhead reservoir and Base
- The base of the basin and the canal
- The channel and the basin
- Runners
- Storage tank
- Pump.

Overhead Reservoir and Base

Designing the tank holder requires consideration of several factors, including the tank's weight and dimensions and ensuring an appropriate height to facilitate the formation of a water vortex. To meet these requirements, the base was created using rectangular iron structures. The following dimensions (height: 211 cm, length: 119 cm, and width: 114 cm) are topped with a water tank with a capacity of 1300 litres. It is connected to two water drainage holes with a diameter of 7.62 cm each. We used one of them because it covered the water needed for the system. The system base is made of a square tube to provide an appropriate height between the source of water coming down from the upper tank and the discharge of water outside to the drainage basin, with dimensions (length 205 cm, width 40 cm, and height 63 cm).

Channel and the Basin

In this study, the basin and the canal were designed in such a way that they could accommodate different variables, as shown in Figure 6. These variables include the height of the turbine, the height of the running water in the channel, and the height of the water vortex inside the basin, where the channel was designed with a width of 10 cm, a length of 125 cm, and a height of 22 cm and the channel was made of galvanized alloy with a thickness of 2 mm. The channel ends with a cylindrical basin with a diameter of 55 cm, a height of 22 cm, and a thickness of 2 mm, and the basin was made of galvanized alloy. In the centre of the basin, there is a drainage hole for water coming out of a vortex with a diameter of 12 cm.

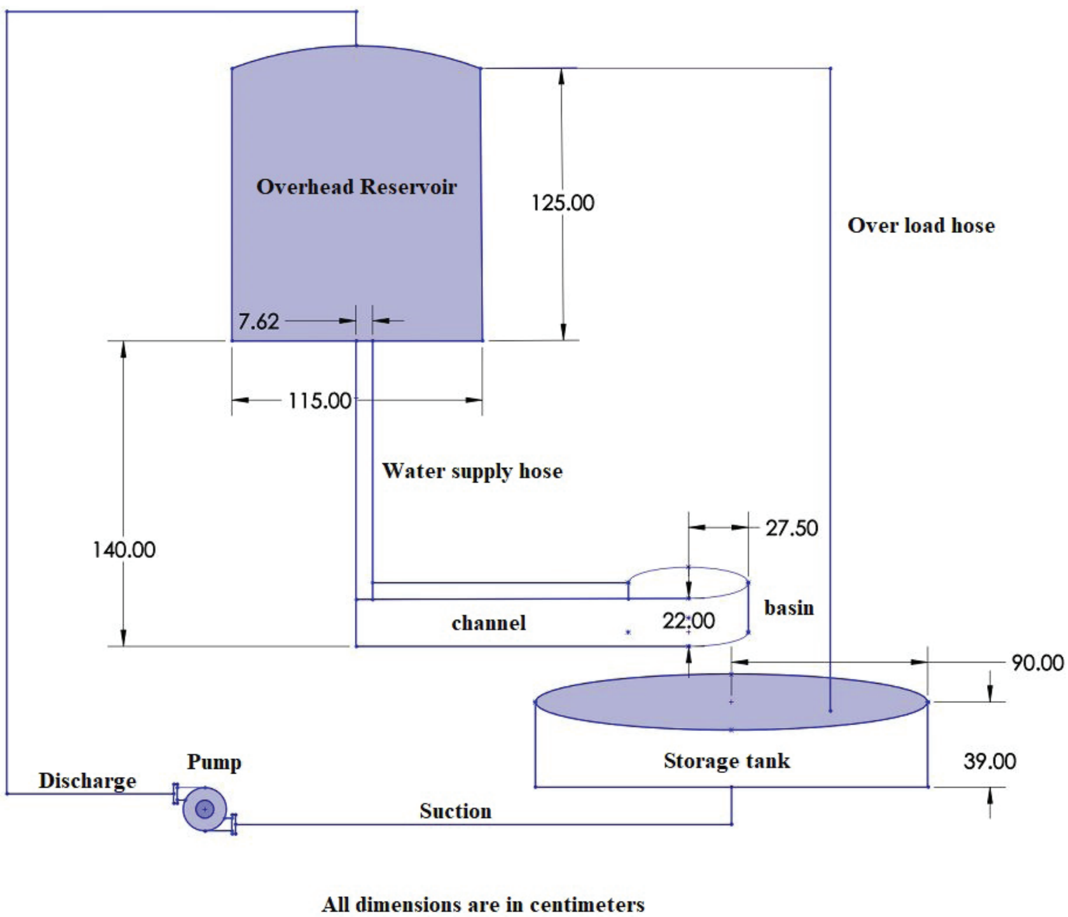


Figure 3. Diagram of system with dimensions.

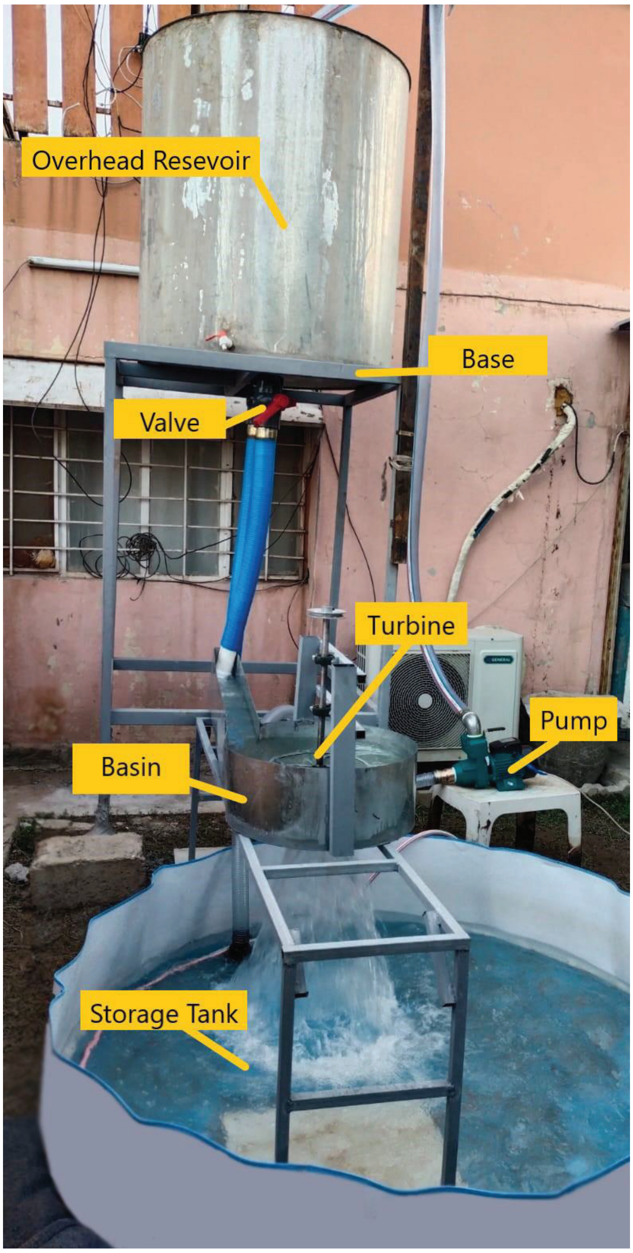


Figure 4. The gravitational water vortex power plant used in the study.

Table 1. Basic dimensions

No	Geometric variables	Value
1	The height of the tank base	211 cm
2	Length of the tank's base	119.5 cm
3	width of the tank's base	114 cm
4	The height of the reservoir from the channel	140 cm
5	Tank diameter	115 cm
6	Tank height	125 cm
7	storage tank diameter	180 cm
8	storage tank height	39 cm

Runner

Four models of turbines were made based on a number of variants, as shown in Figure 7, divided into two groups: the first group consists of two turbines with 4 blades and 6 blades made of galvanized alloy, and the second group consists of two turbines with 4 blades and 6 blades made of carbon steel alloy. The angle between the blades in a four-blade turbine is 90 degrees, the turbine height is 12 cm, and the diameter is 30 cm, and the angle between the blades in a six-blade turbine is 60^{o} degrees, the turbine height is 12 cm, and the diameter is 30 cm. All dimensions are mentioned in Table 1 and 2.

Storage Tank

In this experiment, a basin was used to collect the water coming out of the water vortex system; the dimensions of the basin are as follows: the diameter of the basin is 180 cm, and the height of the basin is 39 cm, where the capacity of the basin is 992.4 liters. A centrifugal-type water pump was used. The pump draws the water collected in the sump and returns it to the tank periodically, where the exit diameter is 5.08 cm. Tables 3 and 4 show a comparison between the turbines used in terms of efficiency, cost, manufacturing material, weight, and Mechanical Properties.

Accessories and Tools Used in the Experiment

A Digital tachometer was used to measure the digital rotational speed, which is usually used to calculate the

Table 2. Basic dimensions of the runners

NO	Geometric variables	Model 1	Model 2	Model3	MODEL 4
1	Internal diameter	2 cm	2 cm	2 cm	2 cm
2	External diameter	30 cm	30 cm	30 cm	30 cm
3	Blade length	15 cm	15 cm	15 cm	15 cm
4	Blade height	12 cm	12 cm	12 cm	12 cm
5	Blade thickness	0.2 cm	0.2 cm	0.2 cm	0.2 cm
6	Blade radius	6.5 cm	6.5 cm	6.5 cm	6.5 cm
7	Material of turbine	Carbon steel	Carbon steel	Galvanize steel	Galvanize steel
8	Number of blades	4	6	4	6

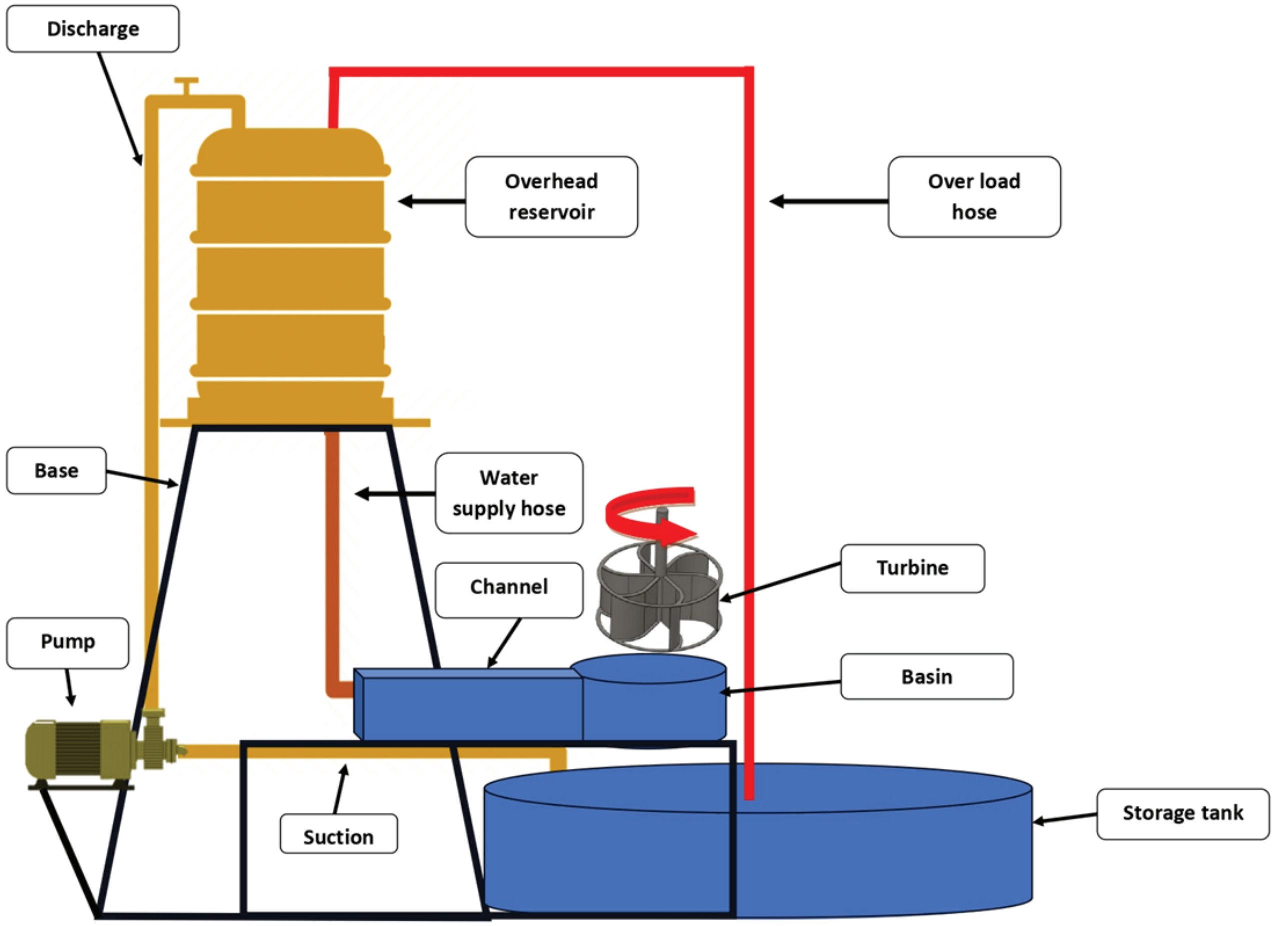


Figure 5. Diagram of the gravitational water vortex power plant used in the study.

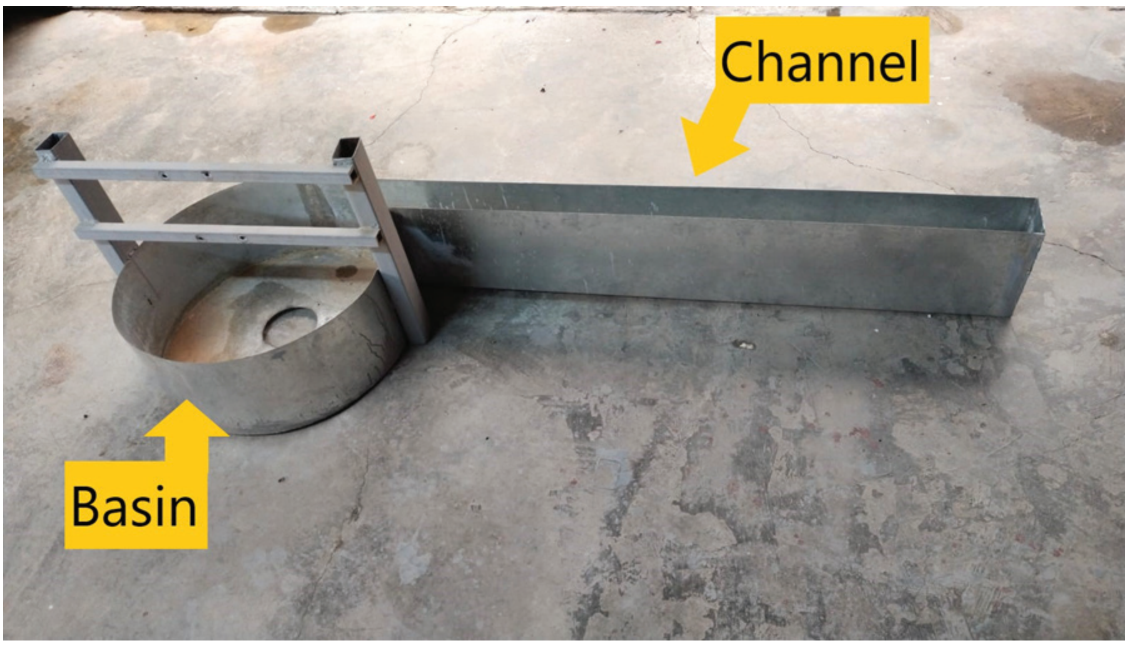
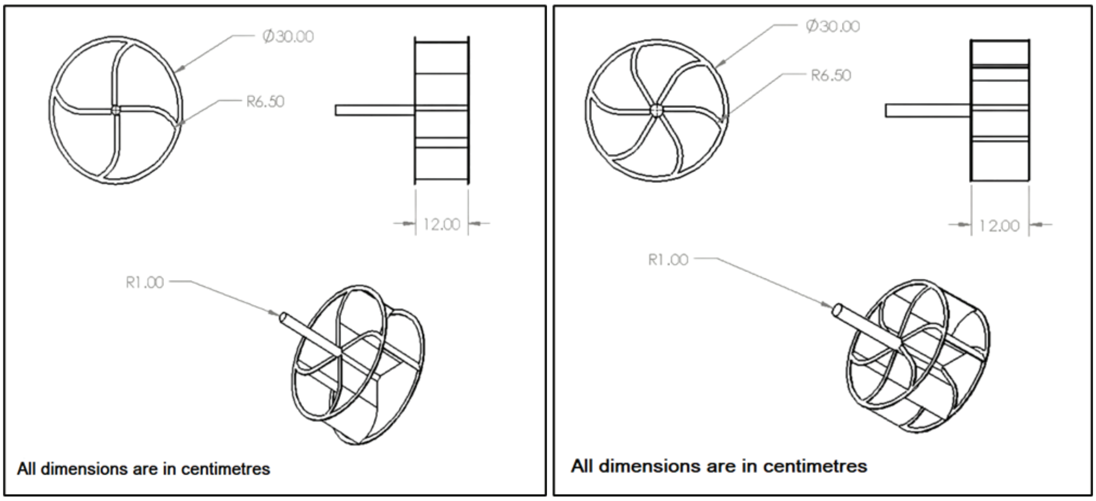


Figure 6. The basin and the channel used in this research.

(a) Photograph of rotor models.



(b) Basic dimensions of the runners.

Figure 7. The runners used in the study.

Table 3. Comparison between the turbines

Items	Turbine	Alloy	Weight	Cost	Height from the bottom of the basin	Efficiency
1	**6-Blade Turbine**	**Carbon Steel Alloy (S5 A105 Gr 1042)**	**2.45 Kg**	**50 $**	**3 Cm**	**64%**
2	**4-Blades Turbine**	**Carbon Steel Alloy (S5 A105 Gr 1042)**	**1.95 Kg**	**40 $**	**3 Cm**	**69%**
3	**6-Blades Turbine**	**Galvanized Alloy**	**2.60 Kg**	**60 $**	**3 Cm**	**51%**
4	**4-Blades Turbine**	**Galvanized Alloy**	**2.10 Kg**	**50 $**	**3 Cm**	**63%**

Table 4. Mechanical properties

Alloy	Tensile strength (psi) min	Yield strength (psi) min	Elongation in 2” (%) min	Brinell Hardness (BHN) max
Carbon Steel Alloy (S5 A105 Gr 1042)	70,000 psi	36,000 psi	22%	187
Galvanized Alloy	79,800 psi	36,300 psi	20%	200

Table 5. Instruments accuracy

Equipment	Test	Range
Flowmeter	volumetric method	±1%
Non-contact tachometer	Rotational speed	±0.1%
Digital spring balance	Weight	±10 gm
Vernier caliper	Dimensions	±0.05 mm

Table 6. Comparison research

Author	Refs	Year	Type study	Efficiency	Our efficiency
Obozov et al.	[2]	2023	Experimental study	56.8 %	69%
Wardhana et al.	[4]	2019	Numerical study	54.40%	69%
Subekti et al.	[15]	2023	Experimental study	45.3%	69%

rotational speed of the shaft or disc in machines. It was used in this research to measure the rotational speed of the shaft connected with each turbine according to the different changes that took place on it, such as its location, the number of blades, and its weight. Digital spring balance was used to measure the torque generated around the poly outside of the turbine by the Prony brake mechanism method by applying variable loads to the rotating shaft of the turbine based on the amount of force required to stop the rotation of the turbine, allowing the measurement of torque. The flow rate of water was measured using the volume method. This method is a simple and effective way to estimate flow rates by calculating the time it takes to fill a bucket of a known size.

Accuracy of Instruments

Table 5 shows the accuracy of all instruments used in the test.

Applications for Our Study

Our study of a large group of previous studies proves the work or application of water vortex stations to generate electricity from low heads ranging from 0.7 meters to 3 meters [22-24].

Our study can also be applied in the laboratory to a detailed study of a turbine and the number of its blades and developed to take advantage of its results in application according to demand and benefit from them on small rivers to help generate electricity.

Comparing our Research with Previous Studies and Research

Our research was compared with the group of researchers studied in previous years ,and the highest efficiency reached by the researcher was chosen. As shown in Table 6.

Performance Calculation

This formula is used to calculate the specific hydraulic power [4]

$$E = g\,Hn \tag{1}$$

Where:-
g: acceleration of gravity (g = 9.81 m/s^2)
Hn: net head (m)

Input power based on vortex height (IHP2) can be calculated as:

$$IHP2 = \gamma\, Hv\, Q \tag{2}$$

Where:- γ = specific weight of the water (N/m^3) , H_v: Vrtex height (m)

The continuity and Navier-Stokes equations governed a steady, incompressible, viscous, and turbulent vortex flow. The following describes these equations in cylindrical coordinates [25]:

$$\begin{aligned}
&\frac{\partial V_r}{\partial r} + \frac{\partial V_z}{\partial z} + \frac{V_r}{r} = 0\\
&V_r\frac{\partial V_\theta}{\partial r} + V_z\frac{\partial V_\theta}{\partial z} - \frac{V_r V_\theta}{r} = \upsilon\left(\frac{\partial^2 V_\theta}{\partial r^2} + \frac{\partial V_\theta}{r\,\partial r} - \frac{V_\theta}{r^2} + \frac{\partial^2 V_\theta}{\partial z^2}\right)\\
&V_r\frac{\partial V_r}{\partial r} + V_z\frac{\partial V_r}{\partial z} - \frac{V_\theta^2}{r} + \frac{\partial \rho}{\rho\,\partial r} = \upsilon\left(\frac{\partial^2 V_r}{\partial r^2} + \frac{\partial V_r}{r\,\partial r} - \frac{V_r}{r^2} + \frac{\partial^2 V_r}{\partial z^2}\right)\\
&V_r\frac{\partial V_z}{\partial r} + V_z\frac{\partial V_z}{\partial z} + \frac{\partial \rho}{\rho\,\partial z} = g + \upsilon\left(\frac{\partial^2 V_z}{\partial r^2} + \frac{\partial V_z}{r\,\partial r} + \frac{\partial^2 V_r}{\partial z^2}\right)
\end{aligned} \tag{3}$$

The vortex height can be calculated using the following formula [26]:

$$Hv = 1.7\frac{V_m^2}{g} \tag{4}$$

Where:-
Hv: is the vortex height
V_m: is the maximum tangential velocity
g: is the gravitational acceleration

The electrical power (W) can be calculated from [27]:

$$Pe = VI \tag{5}$$

Where:-
V: voltage
I: Current
A cylinder's shape defines the vortex motion, and this formula gives its velocity [28]:

$$v = \omega \cdot r \tag{6}$$

where:- ω: angular velocity (rad/sec)
r: the fluid particle's radius measured in meters from the rotational axis.
We can calculate the force & velocity of water through the following equations [29]:

$$F = \sqrt{F_X^2 + F_Y^2} \tag{7}$$

$$Fx = \rho Qr\, Vr\, (\cos\beta + 1) \tag{8}$$

$$Fy = \rho Qr\, Vr\, (\sin\beta) \tag{9}$$

$$Vr = V1 - V0 \tag{10}$$

Where:-
F= Force turbine
Fx= Force of flowing water affecting turbine in axis X
Fy= Force of flowing water affecting turbine in axis Y
Vr= Relative Velocity
$V1$= Velocity of flowing water against moving materials
$V0$= Turbine velocity motion
β= Angle of water turbine
To calculate the useful flow rate (Q) of the GWVPP through the following equation [30]:

$$Q = \frac{\text{volume of the basin}}{\text{time spent to fill the basin}} \tag{11}$$

To calculate the input power, the following equation is used [31]

$$Pin = \rho * g * Hv * Q \tag{12}$$

Where:-
ρ: The density of the water ($\rho = 1000\ kg/m^3$).
g: acceleration of gravity, ($g = 9.81\ m/s^2$).
H_v: vortex height
To calculate the braking torque on the turbine shaft, the following equation is used [2]

$$F = g(G_1 - G_2) \tag{13}$$

Where:-
G_1: mass in kilograms, acquired on the high tension side using digital scales
G_2: mass in kilograms, acquired on the low tension side using digital scales
To calculate the torque on the turbine shaft, the following equation is used:

$$M = F\left(\frac{d_p + d_c}{2}\right) \tag{14}$$

Where:-
dp: diameter of pulley
dc: diameter of cable
To calculate the output power, the following equation is used [30]:

$$P_{out} = M\omega \tag{15}$$

Where:- ω: angular Velocity (rad/s) and calculated from [32]

$$\omega = \frac{2\pi N}{60} \tag{16}$$

The efficiency of the system is determined by the energy conversion of the hydro-turbine as [31]:

$$\eta_{exp} = \frac{P_{out}}{P_{in}} \times 100 \tag{17}$$

RESULTS AND DISCUSSION

A practical study of the system of water vortexes was conducted using two groups of turbines, one of which consists of quad and hexagonal blade turbines, which are made of a carbon-steel alloy. The second group also consists of quad and hexagonal turbine blades, which are made of a galvanized alloy. The study was conducted for turbines at different heights from the bottom of the basin, where it was noted that the highest amount of efficiency was obtained with a height of 3 cm for a turbine from the bottom of the basin, despite both the change in operational and design effects, including the amount of flow and the height of the vortex, as well as the number of feathers and the weight of the turbine. From the experimental results of the previous variables, the maximum efficiency reached 69% when the flow rate was 0.005232 m^3/s and the height of the vortex inside the basin was 18.5 cm.

Influence of the Weight and Height of the Turbine on the Efficiency

Figure 8 shows the effect of the weight and height of the turbine from the bottom of the basin on the efficiency of the turbines, where it was observed that the efficiency reaches its highest values at the height of 1.5 cm and a height of 3 cm and As indicated in the research [33], after which the efficiency begins to decline despite the high ratio of flow rate and the high water level inside the basin and

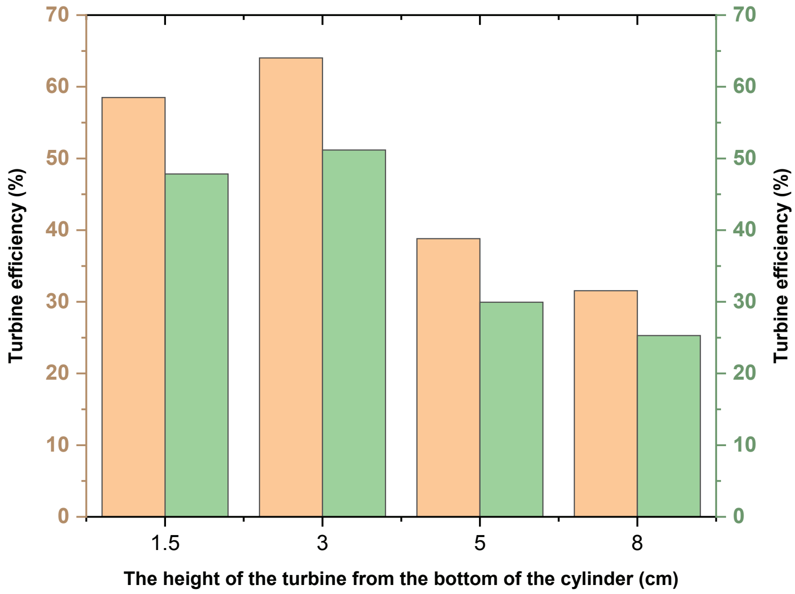


Figure 8. The relationship between efficiency and height.

channel where the level of flowing water covered the upper end of the turbine. The maximum efficiency of the hexagonal-blades turbine with a carbon-steel alloy reached 64 % when the water flow rate was 0.00525 m^3/s, and the flowing water level was 19 cm. After that, the efficiency of the turbine decreases despite increasing the flow rate to 0.006205 m^3/s and the water height to 20 cm. Due to the fact that the speed of water in contact with the bottom wall of the basin is almost zero, according to the laws and concepts, the speed distribution and the effect of water density and due to the friction of water with the bottom wall of the basin, which leads to a change in the shape and profile of the water velocity, which has a major role in the impact and reduces the efficiency of the system or turbine when it is close to the bottom. The same is the case with the six-blade turbine with galvanized steel, where at a height of 3 cm, it reaches the highest efficiency of 51.18% when the flow rate was 0.005212 m^3/s and the water height was 18 cm. When comparing the efficiency achieved by each of the two turbines, we find that the turbine made of a carbon steel alloy with a lower weight is more efficient than the second. This is similar to the results of the effect of weight on efficiency that were reached in a practical study [27]. This is due to the first having a higher torque caused by the inertia of the turbine and the ability of the water vortices generated in the basin to rotate the turbine as a result of the continuous collision of the water with the surface of the turbine blades. This generates a greater force on both sides of the shaft connected to the turbine and ultimately leads to higher efficiency.

The same is the case in Figure 9, it has been noted the four-blade turbine with carbon-steel alloy (S5 A105 Gr 1042) and galvanized alloy is affected by weight and location as well, where we find the highest efficiency recorded for the turbine with carbon-steel alloy at a height of 3 cm 69% at a flow rate of 0.005232 m^3/s and the height of flowing water in the basin and the channel is 18.5 cm. The same is the case with the galvanized alloy four-blade turbine, where the maximum efficiency at the height of 3 cm reaches 63.4% at a flow rate of 0.005043 m3/s and the height of flowing water is 18 cm, efficiency begins to decline in both turbines despite the increase in operational and design effects, and this leads us to search more deeply into understanding the main reasons for the impact of the turbine location on efficiency, torque, and power generated by the turbine. The most important reason is Taylor vortices, which are a type of flow instability that can occur in cylindrical systems when there is a radial flow gradient. This instability affects the efficiency of plant operations by changing flow characteristics and energy distribution within the system. That is, it adds another force to the system in addition to the water vortex force, which grows at a height of 3 cm, where the turbine is trapped between multiple Taylor vortices, and the movement of water molecules within the axis of Taylor vortices adds additional energy to the violence in addition to the energy resulting from the main water vortices. The location of Taylor vortices is shown in Figure 10.

Water Power Entering the System

Figure 11 shows the water power entering the system, which mainly depends on the flow rate of the water, as well as the height of the water inside the basin so that the flowing water completely covers the upper surface of the turbine to ensure water contact with the side area of the Blades. As the height of the turbine increases, the water power gradually increases, starting from 8.4 Watts to reaching 12.17 Watts. This is similar to the interpretation of the

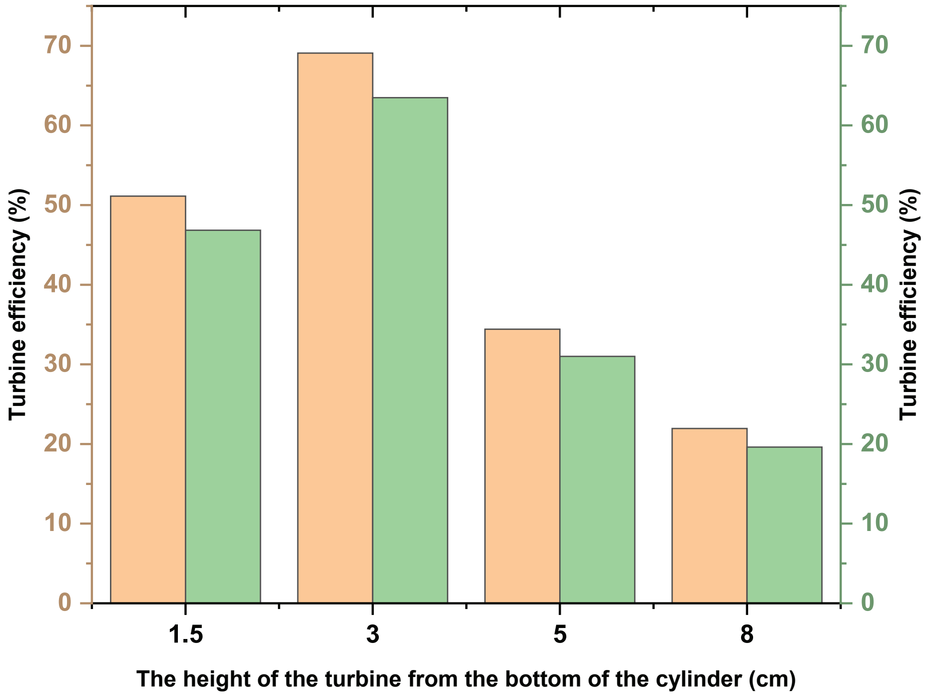


Figure 9. Diagram of the relationship between efficiency and height.

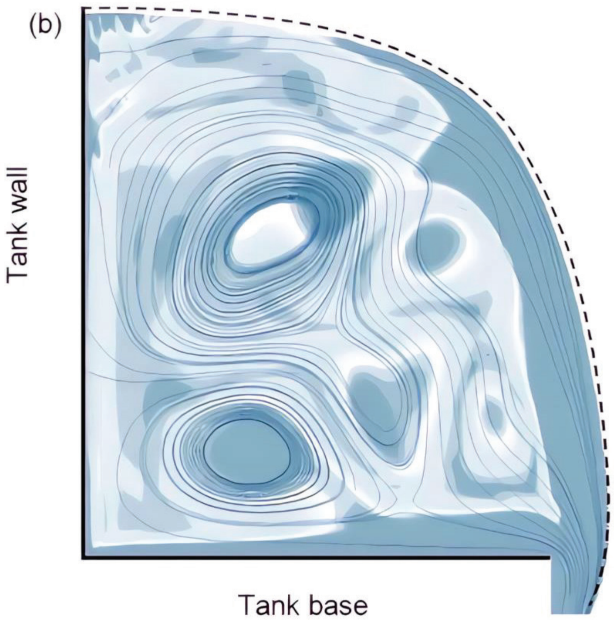


Figure 10. Taylor's vortex and the location of the turbine.

results that increase the efficiency of the system and energy production and referred to in articles such as [34, 35]. The water temperature during the test period ranged between 18 and 20°C, where the water maintains its density during these temperatures, and the increase in the water temperature reduces the density of the water and makes it more susceptible to evaporation. Thus, this affects the flow rate if the study is to install a number of water vortex stations over wide distances within a single river line. Where water passing from the Lower Zab River was used to ensure the quality of the water was similar to the water of the Lower Zab River during the experiment.

Influence of the Number of Blades on the Efficiency

Figure 12 shows the effect of the number of blades of the turbine on the efficiency of the turbine; that is, when increasing the number of blades in the turbine, the surface area exposed to water increases, as well as an effective role to receive the force of water flow and reduce the deformation of the vortex generated inside the basin to a minimum due to its shape. It is necessary to take into account the coordination of the shape and number of turbine blades with the shape and strength of the vortex. Also, increasing the number of blades increases the weight of the turbine. The turbine faces a set of variables that have an important role in determining the efficiency of the turbine, including (the tangential velocity of the water vortex, the height of the turbine and its location of Taylor vortices, weight and inertial torque, vortex deformation, air core, effort applied to the shaft, etc.). When comparing the six-blade turbine with the four-blade turbine at different turbine heights, we note the following: the higher efficiency of the hexagonal turbine at three different turbine heights, where it reaches 58.5% at the height of 1.5 cm, 38.8% at the height of 5 cm, 31.5 at the height of 8 cm, which is higher than the efficiency of the four-blade turbine at these heights, but the four-blade turbine exceeds the efficiency of the hexagonal turbine only

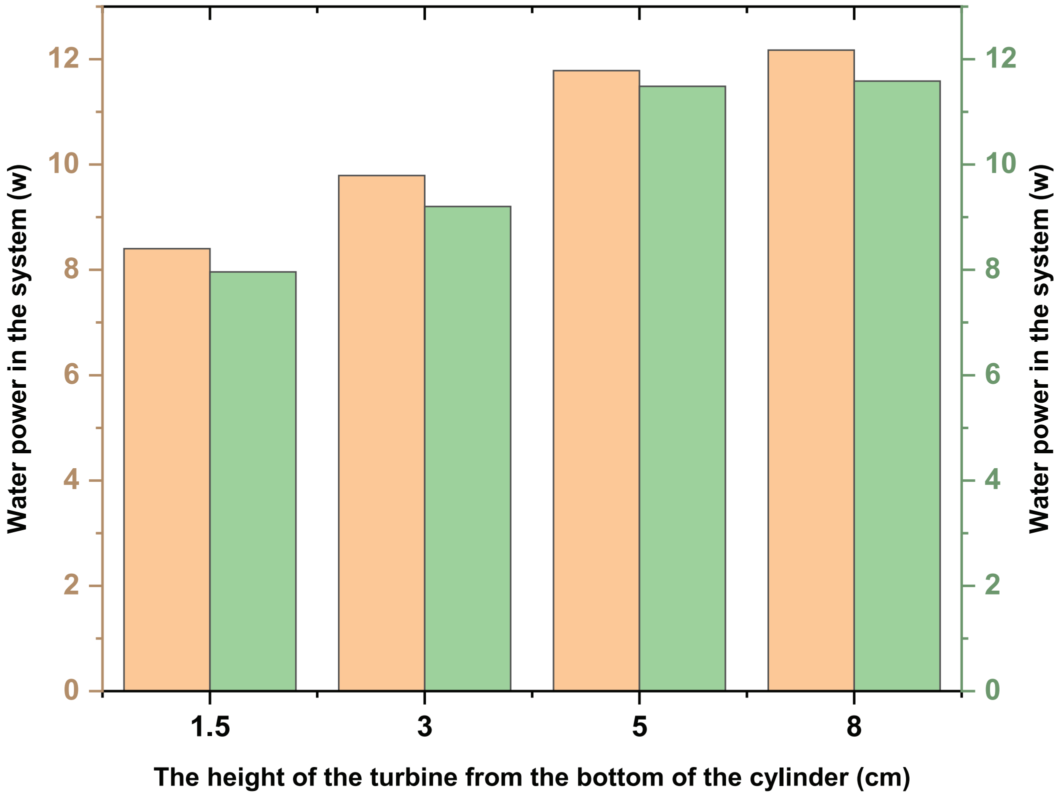


Figure 11. Relationship between turbine height and fluid flow power.

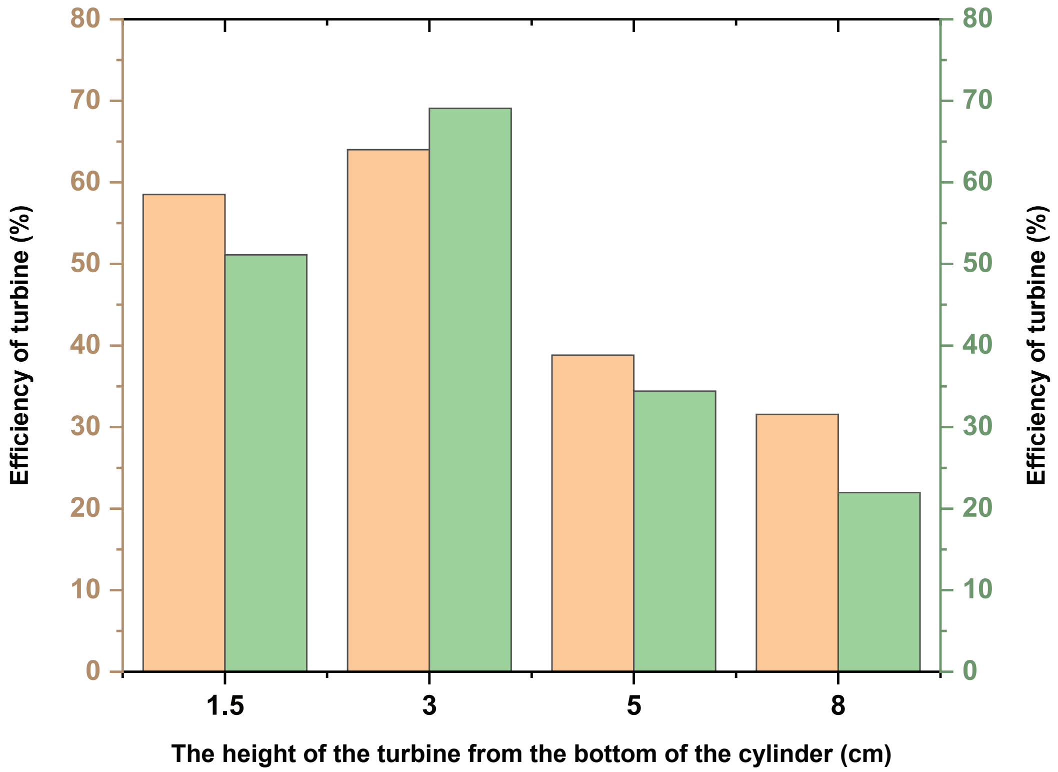


Figure 12. A relationship between the height of the hexagonal and quadrilateral turbine and the efficiency.

5% at the height of 3 cm, where it reaches 69% when the flow rate is 0.0052 m^3/s and the height of the water inside the basin is 18.5 cm. As mentioned in research [4], the number of blades is inversely proportional to efficiency.

Power of the Hydro Turbine

Figure 13 shows the power of the water turbine of two types of turbines, one of them is six-blade. The other is four-blade, where it has been found that the power of the water turbine of the four-blade turbine is higher only at a height of 3 cm, where it is 6.5 watts and less in the others of the heights when compared with the hexagonal turbine, and this is due to the large role of Taylor vortexes generated significantly at a height of 3 cm and overcome other of variables. This allows the quadruple turbine to extract the maximum amount of water energy.

Angular Velocity of Six Blades Turbine and Four Blades Turbine

Figure 14 shows the angular velocity of a six-and four-blade turbine. We find the angular Velocity of the hexagonal turbine at different heights is higher than that of the quadruple turbine, where it reached 10.4 rad /s as its maximum value. Although the power, torque, and efficiency generated in a quad turbine with a height of 3 cm are higher, an increase in the torque applied to the blades leads to a decrease in the angular velocity of the quad turbine blades.

Effect of Flow Rate and Turbine Height on System Efficiency

Figure 15 shows the effect of flow rate and turbine height from the bottom of the basin together on the efficiency of the system. When comparing the effect of flow rate with the impact of turbine location, this effect appears relatively, as increasing the flow rate increases the efficiency of the system to a certain extent, then its effect stops on increasing the efficiency of the system despite its increase, as the effect of the turbine location on efficiency appears.

Compared to the flow rate and turbine height, the effect of efficiency is observed, where the lowest flow rate is 0.0047 m/s, the efficiency was recorded at 47%, and the turbine height was 1.5 cm. The flow rate increased by 0.0052 m/s and at a turbine height of 3 cm, and the efficiency was recorded at 51%. Then an increase in the flow rate was recorded at 0.0054 m/s and at a turbine height of 8 cm, and the efficiency was recorded at 25%. The effect of turbine height appeared at 1.5 cm and 3 cm, where the highest efficiency was recorded, then the efficiency began to decline despite the increase in turbine height and flow rate.

Environmental and Cost Implications

Studying the impact of gravity water vortex power plants on the environment and their cost of important aspects of their development, it was as part of the hydropower energy used to generate electricity, such as dams and others. When compared to photovoltaic cell stations

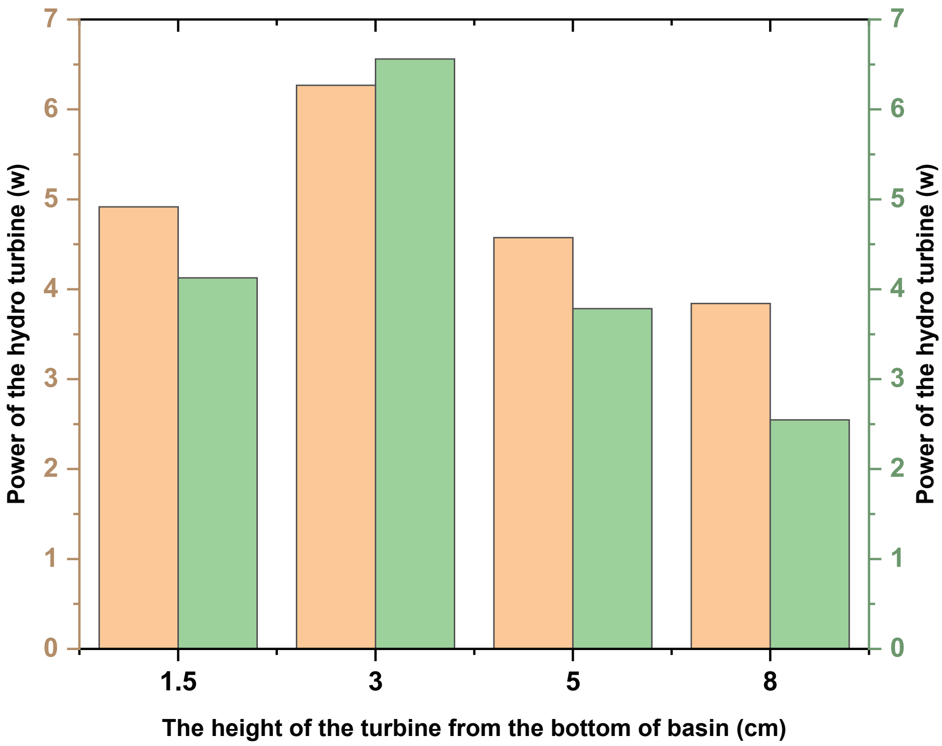


Figure 13. A relationship between the power of the hydro turbine and the height of the turbine.

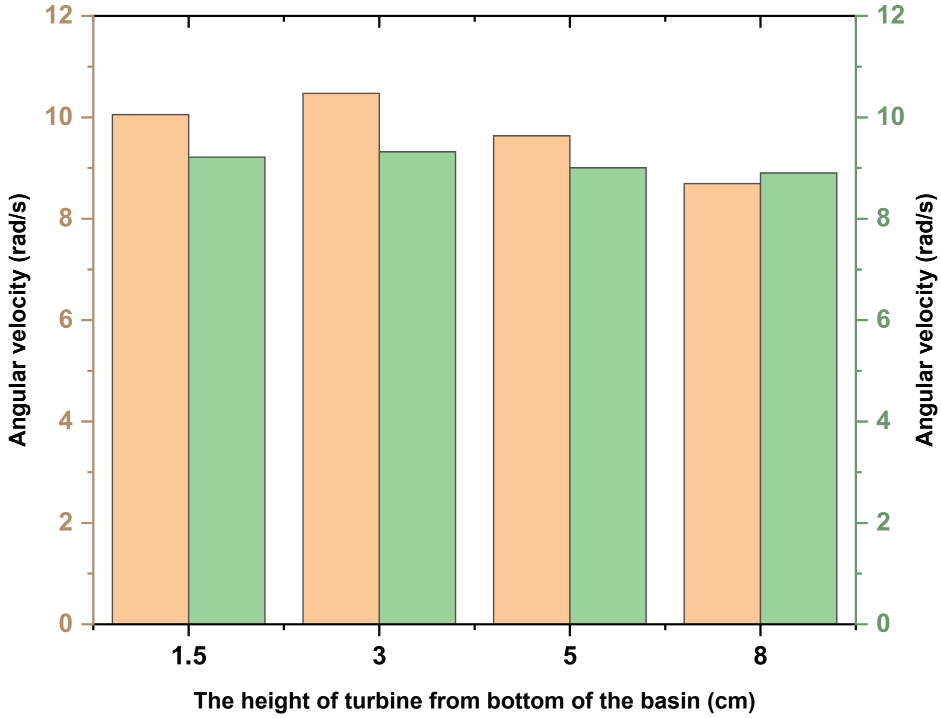


Figure 14. A relationship between angular velocity and height of turbine.

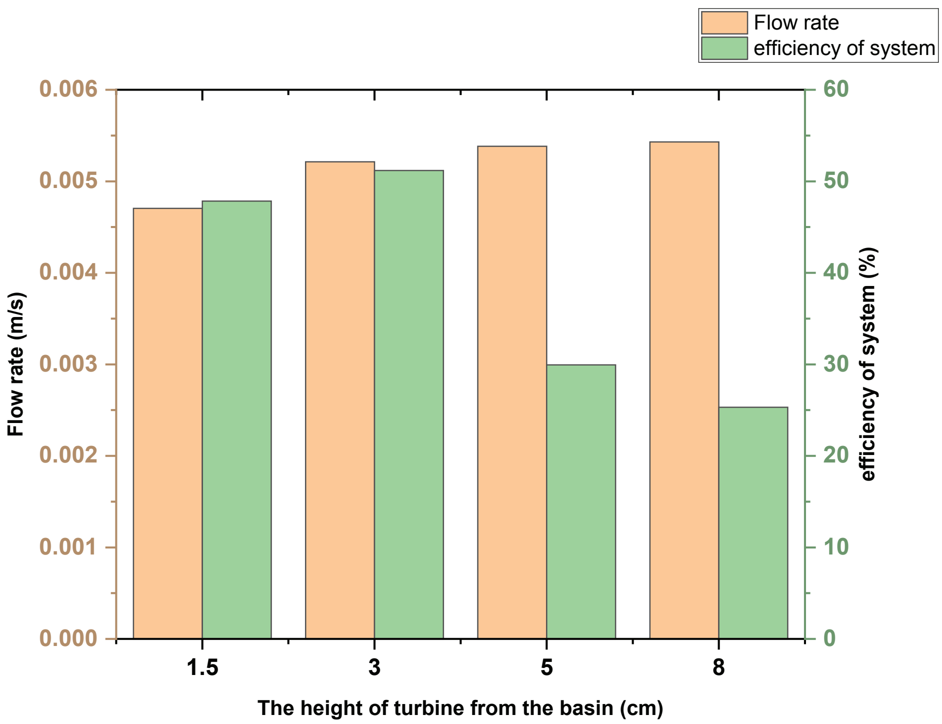


Figure 15. A relationship between flow rate and height of turbine.

(solar energy), hydropower stations are available throughout the day, unlike solar power plants, which provide their energy only at limited times during the day. The same is true when compared to dams, as dams require expensive construction costs and specialized companies for design, construction, and periodic maintenance, which have very expensive costs, as well as the danger posed by dams from collapses and displacement of residents to distant areas, as well as their role in earthquakes. In contrast, gravity water vortex power plants are easy to install, fabricate, and maintain. Many environmental advantages apply, such as water ventilation, fish passage and preservation [36], and the lack of need for large dams. They are also applied to low-pressure hydropower [37]. Globally, mountainous areas and sites adjacent to rivers and lakes can benefit greatly from producing small hydroelectric power on a smaller scale. Gravity vortex turbines are one of the new hydroelectric technologies used to generate electricity [31].

CONCLUSION

It has been concluded from the results obtained the following:

1. The energy extracted from the water vortex turbine increases to a certain extent with the increase of the number of blades, and then the efficiency decreases with the rise of blades.
2. The weight of the turbine is instrumental in determining the efficiency of the system, as it has an inertial torque that faces the force generated on both sides of the shaft most of the time, in addition to generating higher torque at different heights and locations and lower torque at some heights.
3. The tests carried out also showed that the best height of the turbine from the bottom of the basin is 3 cm as a result of the active role of Taylor vortexes. The maximum efficiency of a hexagonal turbine made of a carbon steel alloy reached 64%, and the maximum efficiency of a quadruple turbine made of a carbon steel alloy reached 69%, 51.8%, and 63.4% in turbines made of a galvanized Hexagonal and quadruple alloy, respectively.
4. It is preferable to retest the system numerically under different operating and design conditions such as flow rate and hydraulic height waters as well as using the notch at different angles and study the effect of each in detail on the system.
5. Use alternative manufacturing alloys for made turbine that have the ability to work in an water medium. like aluminum and bronze.
6. Benefit from future technological developments in developing and improving the efficiency of the water vortex system such as:-

- Improving the turbine design by studying the principles of advanced fluid dynamics to benefit from the greatest amount of water energy.
- Relying on 3D printing to produce different shapes of turbines with greater efficiency and very low cost.
- Using different batteries and storage technologies such as solid or lithium batteries to benefit from times of high demand.
- Using smart control systems and advanced sensors to improve monitoring and directing water in real time, which increases the efficiency of the station.
- Environmental impacts to consider when improving vortex turbines
- The turbine should be designed in a way that allows fish to pass through it without being injured.
- Creating strong vortices may affect small fish or other aquatic organisms
- Turbines may affect the flow of water and this may affect the suitable conditions for aquatic life of plants and animals.
- Reducing noise and vibrations resulting from turbines that have a role in affecting animals near the water.
- Preserving the natural beauty through the design of the turbine or plant.

NOMENCLATURE

GWVPP	*Gravitational Water Vortex Power Plants*
CFD	*Computational Fluid Dynamics*
Hn	*net head (m)*
γ	*specific weight of the water (N/m³)*
Hv	vortex height (m)
P_{elec}	*Electrical power (W)*
ω	*angular Velocity (rad/sec)*
β	*Angle of water turbine*
F	*Force turbine (N)*
Fx	*Force of flowing water affecting turbine in axis X (N)*
Fy	*Force of flowing water affecting turbine in axis Y (N)*
Vr	*Relative Velocity*
V1	*Velocity of flowing water against with moving materials*
*V*0	*Turbine velocity motion*
ρ	*The density of the water(kg/m³)*
g	*acceleration of gravity (m/s²)*
G1	*mass in kilogram's, acquired on the high tension side using digital scales*
G2	*mass in kilogram's, acquired on the low tension side using digital scales*
M	*the torque on the turbine shaft (Nm)*
dp	*diameter of pulley (cm)*
dc	*diameter of cable (cm)*
η_{exp}	*The efficiency of the system %*

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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