Effect of hole diameter and basin size on the vortex gravity system

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Abstract. The vortex gravity system consists of a tube basin, a canal (worksection) and a water tank. Water is pumped into the upper tank and flowed into the canal by opening the valve which then hits the tube basin and creates a whirlpool. The water that hits the tube and enters the outlet hole goes down to the lower tank and is circulated back to the upper tank. The outlet hole in the tube has 4 sizes and the tube size has 3 sizes. This study is based on experimental tests to determine the flow performance of the outlet diameter of the tube against the formation of vortices in the vortex tube. From several existing studies, the type of outlet hole in this tube has not been thoroughly studied. From the analysis results, it can be seen the difference in the results of each outlet size in the tube basin. With this question, this study aims to determine the strength of the vortex of the parameters that must be looked for, namely Water Flow Discharge (m\textsuperscript{3} / s), velocity (m / s), and Total Head Water (m). The vortex gravity system on a laboratory scale, based on previous studies or studies varying the diameter of the vortex tube and tube outlet hole, this study examined the effect of differences on the diameter of the vortex tube and the outlet hole of the tube basin. From the calculation of the vortex strength at the outlet hole of 25 cm, the results of the vortex strength are 7.53 m\textsuperscript{2} / s; 22.60 m\textsuperscript{2} / s; 45.21 m\textsuperscript{2} / s; 52.75 m\textsuperscript{2} / s. After that, proceed with the calculation of the outlet hole of 30 cm, the results of the vortex strength are 12.24 m\textsuperscript{2} / s; 28.26 m\textsuperscript{2} / s; 45.21 m\textsuperscript{2} / s; 56.52 m\textsuperscript{2} / s. Furthermore, the calculation at the 35 cm outlet hole obtained the vortex strength of 14.13 m\textsuperscript{2} / s; 30.14 m\textsuperscript{2} / s; 42.39 m\textsuperscript{2} / s; 60.28 m\textsuperscript{2} / s. the occurrence of fluctuation in the vortex strength results due to the energy available in the extracted water flow after hitting the outlet hole in the vortex tube. The graph produced in this calculation shows that the highest vortex strength occurs in a tube with a diameter of 35 cm.

1. Introduction

The Water Vortex Gravity Power Plant (GWVPP) is a generating system that generates electricity from a vortex water turbine with a low height and low flow rate. The vortex gravity system consists of a tube basin, a canal (work section) and a water tank. Water is pumped into the upper tank and flowed into the canal by opening the valve which then hits the tube basin and creates a whirlpool. The water that hits the tube and enters the outlet hole goes down to the lower tank and is circulated back to the upper tank \cite{1}. Despite the fact that the outlet holes in the tubes are of different sizes, the perfect vortex formation can occur in certain tube sizes. From several studies that there have been various sizes of the tube and the outlet hole of this tube has not been studied in depth. To increase the velocity and the formation of the eddy strength, a study of the flow of the open channel is needed to determine the sizing characteristics of the tube and the tube outlet.
Given this background, this study aims to design tools and conduct experiments on vortex gravity models and determine the effect of the diameter ratio of the vortex tube and the outlet of the vortex tube to the height and velocity of the vortex flow. Furthermore, checking the strength of the vortex generated around the outlet hole of the tube requires a simulation experiment using the Inventor software as a visual representation of the laboratory-scale vortex gravity system model.

Hydroelectric power is one way to take advantage of renewable energy sources, but its utilization is still on a small scale and uses simple technology as a generating system that can meet the required electrical energy. This type of hydroelectric power is often called microhydro or often called Pico hydro depending on the electricity output generated by the generator. Microhydro which usually uses waterfalls with high water falls. Meanwhile, the height and fall are not maximally utilized. This is a reference for utilizing river flow by converting it into a vortex flow.

A researcher from Germany Viktor Schauberger developed vortex flow technology (vortex) to be applied to water turbine modelling. Vortex flow, also known as pulsating or vortex flow, can occur in a fluid flowing in a channel that undergoes sudden changes. The phenomenon of vortex flow is often found in airplane wing modelling, vortex flow tends to be considered a loss in a fluid flow. Starting from the conditions above, it is necessary to conduct research to see the effect of tube dimensions and discharge on vortex formation.

Sarkardeh conducted experimental modelling to investigate the effects of head walls and trash shelves on vortices [2]. Acoustic Doppler Velocimetry is used to determine velocity and circulation profiles. The authors determine the relationship between strength and vortex type. Recently, Yang conducted dimensional analysis and experimental modelling to determine the effect of the intake-entrance profile on critical submergence [3]. The authors tested eight entrance profiles and found that the square edge profile produced the highest local head losses. Li and Wang, and all successfully used particle imaging techniques to investigate air core vortices in hydraulic intakes [4] [5]. Carriveau conducted extensive studies on the evolutionary mechanisms of free-surface vortices as well as axial stretching [6].

Further researchers who became the research literature "Experimental and Numerical Analysis of Free-Surface Turbulent Vortex Flows with Strong Circulation" vortex system determines the vortex strength which is influenced by differences in several variations of outlet holes in the tube basin. This data will be used as a reference to determine vortex strength [7].

The research of Fajar Sumantri and Muhamad Fitri aims to design a vortex test device that determines the working system of the tool so that it can be used to observe free vortices and forced vortices in water. This vortex tester is designed with a water outflow velocity of 2.425 m/s and a flow rate of 73.8 liters / minute [8].

Subsequent research Javed Ahmad Chattha The Water Vortex Turbine generator determined that the performance of the propeller rotor that is positioned is higher than the rotor located below it, thus showing that undistorted surface eddies have more energy available for power generation. To build multi-staging in GWVT, this study suggests using the same propeller and optimal setting distance [9].

1.1. Overall design
In this study, a vortex system is used without using a turbine. Prior to data collection, a set-up was carried out by connecting each component so that it became a vortex system.
Carried out in this study is to take data from tools that have been assembled on several variations of the diameter of the vortex tube with the appropriate measuring instrument. The parameters required include discharge, velocity, head worksection (channel) on the quality of vortex formation and the strength of the vortex produced. Based on the experimental results of this study, it can be used as a reference in further studies in laboratory scale vortex systems.

2. Method

Experimental tests of the vortex system using 4 experimental variations in the vortex tube outlet holes were carried out next to the Energy Engineering Laboratory, Mechanical Engineering Department, Faculty of Engineering Physics, Faculty of Industrial Technology and Systems Engineering. Measurements carried out in this study include measuring the velocity of the vortex in the vortex tube using a Flow Meter from JDC Flowatch.

Before testing the vortex system and collecting data, checking is first carried out on several installations and equipment, which includes:

a. Check the water discharge in the lower tank and upper tank
b. Check of the connecting pipe between the feed pump and the gutter.

Vortex tube examination according to the size of the tube diameter and the outlet of the vortex tube.
d. Feed pump check.

After the inspection procedure of some of the above installations and equipment has been carried out and the inspection is confirmed to be in standby condition, the testing procedure can be started. The experimental test procedure for the vortex system with tubes with a diameter of 25, 30, 35 cm

2.1 Retrieval of Data

This research begins with experimental tests carried out on a canal (work section) and an acrylic vortex tube that can be changed by variations in the diameter of the tube and the outlet diameter of the vortex tube.

| Variation Table on acrylic vortex tubes | Variation of the outlet diameter of the vortex tube (cm) |
|----------------------------------------|----------------------------------------------------------|
| Variation of tube diameter (cm)        |                                                          |
| 25                                     | 3                                                         |
| 30                                     | 6                                                         |
| 35                                     | 9                                                         |

In this experimental test stage, to obtain various flow rates, the velocity measurement on the vortex tube was carried out several variations in table 1 using a Flow Meter from JDC Flowatch as shown in the figure.
Flow velocity sampling was carried out in 12 variations. The flow velocity obtained was 4 variations of the outlet diameter of the vortex tube in the tube diameter of 35 cm and the other two were the diameter of 30 cm and 25 cm as shown in Table 2. After determining the variation that will be used for testing, the next step is to measure the worksection area (channel) and the vortex tube. In this research, using worksection (canal) and vortex tube made of acrylic with predetermined dimensions to perform experimental tests. The form of worksection (canal) and vortex tube made of acrylic used in this study is shown in Figure 3.

3. Results and discussion

3.1 Flow discharge test on channel (worksection)
Flow discharge over triangular sharp lintels designed to meet the requirements can be calculated based on the following equation.

\[ Q = v h b \]  

Information:
\( Q \) = discharge (m\(^3\)/s)
\( v \) = flow velocity (m/s)
\( h \) = flow height (cm)
\( b \) = channel width (worksection)
Table 2. Canal discharge on tubes with diameter 35 cm, 30 cm, 25 cm.

| Hole Size | Velocity of the tube 25 | Velocity of the tube 30 | Velocity of the tube 35 | Flow of the tube 25 | Flow of the tube 30 | Flow of the tube 35 | Discharge of tube 25 | Discharge of tube 30 | Discharge of tube 35 |
|-----------|-------------------------|------------------------|------------------------|------------------|------------------|------------------|-------------------|-------------------|-------------------|
| 3 cm      | 0.8                     | 1.3                    | 1.5                    | 6                | 6                | 6                | 20                | 96                | 156               | 180               |
| 6 cm      | 1.2                     | 1.5                    | 1.6                    | 5.5              | 5.5              | 5                | 20                | 132               | 165               | 160               |
| 9 cm      | 1.6                     | 1.6                    | 1.5                    | 5                | 5                | 4.5              | 20                | 160               | 160               | 135               |
| 12 cm     | 1.4                     | 1.5                    | 1.6                    | 4.5              | 4.5              | 4                | 20                | 126               | 135               | 128               |

Figure 4. Graph of Discharge on each tube diameter

3.2 Velocity Test
The measurement in this study aims to determine the velocity generated in several variations in each size of the vortex tube. This measurement is carried out 4 data retrieval which will later be averaged so that it can be used as a comparison chart. In one data collection on one size of the vortex tube, 4 variations were made of the outlet diameter of the vortex tube so that 12 measurements were obtained. On variations in the outlet diameter of the vortex tube.

In order to analyze the directional velocity of the flow, a measuring line is set in position on each part of the water surface. To find a suitable outlet diameter, the tangential velocity and radial velocity are calculated. The distribution of the velocity vectors on the measuring line is shown in Figure 5 which is a top view of the vortex housing. The distribution of velocity is shown on line 1, line 2, line 3, and line 4. Computerized fluid dynamics simulations run with no slip on the wall and with exit pressure at the exhaust hole.
**Figure 5.** The top view of the tube basin where the position of the measuring line on each part is shown at point 1, point 2, point 3, and point 4

**Table 3.** Velocity measurement on the outlet diameter of the vortex tube

| Hole Size (cm) | Tube Diameter 25 cm | Tube Diameter 30 cm | Tube Diameter 35 cm |
|---------------|---------------------|---------------------|---------------------|
|               | v1      | v2      | v3      | v4      | v1      | v2      | v3      | v4      | v1      | v2      | v3      | v4      |
| 3 cm          | 0.7     | 0.6     | 0.5     | 0.4     | 0.4     | 0.6     | 0.8     | 0.7     | 0.6     | 0.7     | 0.9     | 1       |
| 6 cm          | 0.8     | 0.6     | 0.5     | 0.7     | 1.7     | 1.1     | 1.9     | 0.8     | 0.8     | 0.6     | 0.7     | 0.7     |
| 9 cm          | 0.8     | 1.1     | 0.8     | 0.9     | 1.1     | 1       | 1.2     | 1.1     | 0.5     | 0.6     | 0.7     | 0.8     |
| 12 cm         | 0.9     | 0.8     | 0.9     | 0.8     | 1.4     | 1.2     | 1.3     | 1.5     | 0.7     | 0.6     | 0.4     | 0.7     |

Based on Figure 5 above, it can be concluded that the greatest fluid velocity is at the outlet hole 3 cm, then 6 cm, 9 cm and the next 12 cm. Comparison of the average speed at each exhaust can be seen in Table 4 and Figure 6 Graph below.

**Table 4.** Average measurements of the outlet diameter of the vortex tube.

| Hole Size (cm) | Tube Diameter 25 cm | Tube Diameter 30 cm | Tube Diameter 35 cm |
|---------------|---------------------|---------------------|---------------------|
| 3 cm          | 0.55               | 0.625               | 0.8                 |
| 6 cm          | 0.65               | 1.375               | 0.7                 |
| 9 cm          | 0.9                | 1.1                 | 0.65                |
| 12 cm         | 0.85               | 1.35                | 0.6                 |

**Figure 6.** Graph of average Velocity on the vortex system testing
After doing 3 data retrieval it can be concluded with the average results shown in Figure 6. The rotational force (torque) generated by the shaft acting on the water flow which hits the outlet diameter of the vortex tube causes a whirlpool in the tube.

For the four vortex tube outlet diameter conditions, the inlet flow rate is lower than the outflow rate when a new vortex is formed. Therefore, the height of the vortex will decrease and remain constant when the outflow rate drops to the value of the inlet flow rate. The inflow rate is greater than the outflow rate when a new vortex is formed. Therefore, the vortex height increases, the vortex strength increases, and the outlet flow rate remains almost constant. This explains why the vortex height can be very different as the inflow rate increases.

Figure 6 shows that velocity has increased in tubes with a diameter of 35 cm and fluctuates in tubes with a diameter of 30 cm and 25 cm. The velocity graph in this test shows that the highest velocity occurs in a tube with a diameter of 30 cm. The calculation result of velocity is used to determine the vortex strength calculation.

### 3.3 Vortex strength analysis

Vortex Strength is the meter squared per second of water that forms a vortex in the basin hitting the outlet hole.

\[
rv = \frac{2\pi r_i n Q}{b h_i n}
\]

Where:
- \(a = p1 \cdot p2\) (m²)
- \(Q = \text{discharge} = a \cdot v\)
- \(v = \text{velocity (m/s)}\)
- \(b = \text{channel width (m)}\)
- \(D_{eff} = \text{outlet diameter (m)}\)
- \(h_i n = \text{water level in the canal (m)}\)
- \(r_i n = \text{radius inlet (m)} = \frac{D+b}{2}\)
- \(h = \text{water level in the canal (m)}\)

![Figure 7. Vortex system schematic.](image)
\[ rv = \frac{2\pi rinQ}{bhin} \]
\[ = \frac{2\pi rinAV}{bhin} \]
\[ = \frac{2\pi rinbhV}{bh} \]

By using the formula above, the results of the vortex strength chart below are obtained.

**Figure 8.** Vortex Strength chart tube diameter 25cm.

In Figure 8 above we can see the results of vortex strength graphs in each variation of basin tube sizes and outlet holes. For vortex strength it can be explained that there is a decrease in the large outlet hole to the small hole. The test was continued by changing the tube outlet holes from 6, 9, 12 to a drastic drop in the 3 cm outlet hole. This test can determine the results of the vortex strength at each variation in the outlet diameter of the vortex tube. From the calculations for each outlet hole 25 cm, the vortex strength results are 7.53 m\(^2\)/s; 22.60 m\(^2\)/s; 45.21 m\(^2\)/s; 52.75 m\(^2\)/s.

**Figure 9.** Vortex Strength graph of 30cm tube diameter.

In Figure 9 above, you can see the results of the vortex strength graph in each variation in the size of the tube basin and outlet hole. For the strength of the vortex, it can be explained that there is a decrease in the large outlet hole to the small hole. The test was continued by changing the tube outlet holes from 6, 9, 12 to a drastic drop in the 3 cm outlet hole. This test can determine the results of the vortex strength at each variation in the outlet diameter of the vortex tube. From the calculations for each outlet hole 30 cm, the vortex strength results are 12.24 m\(^2\)/s; 28.26 m\(^2\)/s; 45.21 m\(^2\)/s; 56.52 m\(^2\)/s.
In Figure 10 above, you can see the results of the vortex strength graph in each of the variations in the size of the tube basin and outlet hole. For vortex strength it can be explained that there is a decrease in the large outlet hole to the small hole. The test was continued by changing the tube outlet holes from 6, 9, 12 to a drastic drop in the 3 cm outlet hole. This test can determine the results of the vortex strength at each variation in the outlet diameter of the vortex tube. From the calculations for each outlet hole 35 cm, the vortex strength results are 14.13 m²/s; 30.14 m²/s; 42.39 m²/s; 60.28 m²/s.

Table 5. Canal vortex strength table on tubes 35cm, 30cm, 25cm in diameter.

| Hole Size (cm) | Q tube 25 | Q tube 30 | Q tube 35 | Rv tube 25 | Rv tube 30 | Rv tube 35 |
|---------------|-----------|-----------|-----------|------------|------------|------------|
| 3 cm          | 96        | 156       | 180       | 7.536      | 12.246     | 14.13      |
| 6 cm          | 132       | 165       | 160       | 22.608     | 28.26      | 30.144     |
| 9 cm          | 160       | 160       | 135       | 45.216     | 45.216     | 42.39      |
| 12 cm         | 126       | 135       | 128       | 52.752     | 56.52      | 60.288     |

Figure 11. Graph of Vortex Strength on each tube diameter.

In table 5 above, we can see the results of the calculation of the vortex strength in each tube basin and outlet hole size variation. For the strength of the vortex, it can be explained that there is a decrease in the large outlet hole to the small hole. The test was continued by changing the tube outlet holes from 12, 9, 6 to a drastic drop in the 3 cm outlet hole. This test can determine the results of the vortex strength at each variation in the outlet diameter of the vortex tube.

The inlet width \(b\) becomes so small that the viscous effect limits the inlet velocity or the velocity increases towards a supercritical value resulting in energy dissipation via hydraulic jumps downstream of the inlet. The result of this variation changing the hole in the vortex tube outlet will give a significant reduction in the formation of a vortex tube in the vortex system in one circulation. The inlet radius \(r\)
becomes so large that the local tangential velocity in the far field is dissipated and fails to affect the near field.

Where \( Q = \) the discharge entering the vortex system, \( R_{in} \) is the radius of the outlet, where \( b \) is the width of the channel, \( H_{in} \) is the water level in the channel, \( Q \) is a multiplied by velocity and \( R_{in} \) is half of the sum of \( d \) and \( b \). Experimentally, testing the vortex system using flowing water to form a vortex flow. Water will flow through the canal and fill the tank and exit through the exhaust hole until it forms a vortex flow. Based on equation (2), it can be seen that the results of the vortex strength are in table 5 where if the size of the outlet hole in the tube basin is large, the resulting vortex strength is also large. Conversely, if the size of the outlet hole in the tube basin is small, the resulting eddy strength is also small.

4. Conclusions
From the experimental tests on circular vortex basin tubes with dimensions of height 50 cm and tank diameters 35, 30, 25cm and variations in the diameter of the exhaust hole 12, 9, 6 cm and 3 cm. Based on the results of research and analysis that has been done, it can be concluded that:

a) A laboratory scale miniature vortex canal system has been made and it has been tested using various predetermined variations.

b) From the calculation of the vortex strength at the outlet hole of 25 cm, the results of the vortex strength are 7.53 m²/s; 22.60 m²/s; 45.21 m²/s; 52.75 m²/s. After that, proceed with the calculation at the 30cm hole outlet, the results of the vortex strength are 12.24 m²/s; 28.26 m²/s; 45.21 m²/s; 56.52 m²/s. Furthermore, the calculation of the 35cm hole outlet results in the vortex strength of 14.13 m²/s; 30.14 m²/s; 42.39 m²/s; 60.28 m²/s.

c) From the results obtained vortex strength where if the size of the outlet hole in a large basin tube then the strength of the whirlpool produced is also large. Conversely, if the size of the outlet hole in the tube basin is small, the resulting eddy strength is also small.

d) From the results of testing variations in the outlet diameter of the vortex tube of 3 cm resulted in a longer and perfectly formed whirlpool.

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