International Journal of Mechanical and Production Engineering, ISSN(p): 2320-2092, ISSN(e): 2321-2071
Volume- 7, Issue-9, Sep.-2019, http://iraj.in

# EXPERIMENTAL INVESTIGATION OF A WATER VORTEX POWER PLANT – PERFORMANCE AND DEGREE OF EFFICIENCY

**[1]RIZWAN GHANI, [2]NADINE MULLER, [3]JURGEN STAMM**

[1,2,3]Institute of Hydraulic Engineering and Technical
Hydromechanics, TU Dresden, Germany
E-mail: [1]rizwanghani121@gmail.com, [2]Nadine.mueller@tu-dresden.de, [3]juergen.stamm@tu-dresden.de

**Abstract** - The demand for renewable sources of energy is increasing every day. The use of non-renewable sources of energy is being phased out due to its negative environmental impacts. Therefore, there is an urgent need to find alternative sources of energy. A water vortex power plant, which is the object of this study, is a low head hydropower plant, which works on the principle of vortex flow. The surveyed water vortex power plant operates at low speeds up to 30 rpm. An experimental study was conducted to find the influencing parameters on the power and efficiency of the water vortex power plant. Firstly, a detailed literature review has been carried out to study the past work done in the area. Next, experiments have been conducted on the vortex power plant model. A set of parameters were varied to find the dominant parameters affecting the efficiency of water vortex power plant. By analyzing results from suitable experiments, the dependency of parameters on the water vortex power plant was found. A performance curve is identified for the optimum generation of electrical power from this power plant. Based on the results, recommendations have been made for increasing the efficiency of the power plant.

**Keywords -** Efficiency, Generator Curve, Laboratory Model, Micro Hydropower, Performance.

## I. INTRODUCTION

Hydropower is considered as the biggest source of renewable energy in the world(6). The total installed capacity of hydropower in the world is estimated to be about 1.2 TW (6). In recent times, the use of small and micro-hydropower has gained considerable importance due to its environment-friendly nature, low construction period and cheap installation and maintenance costs. Small hydropower plants can be especially very beneficial for far off areas like developing countries. Water vortex power plants offer promising results in the field of renewable energy. According to Zotlöterer, in Europe, there exists potential for constructing 5 million water vortex power plants with a total capacity of 100 GW (17). Before the water vortex power plant can be proffered as a reliable market solution in the hydro-power sector, it is necessary to have a deeper understanding of the working of the water vortex power plant and its performance characteristics. There is a considerable dearth of research in the field of water vortex power-plants (15). Although there have been considerable advances in the field of small hydropower in terms of increasing the efficiency of hydropower turbines, the water vortex power plants have been less studied. Consequently, it is imperative to carry an in-depth study in the field of water vortex power plant technology.

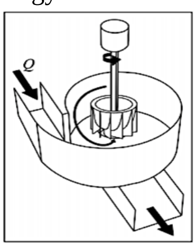


**Figure 1.: Water vortex power plant: Functional diagram (7)**

Water vortex turbines work on the dynamic force of vortex flow. The water moves from a large inlet and is directed tangentially into a round basin (Fig. 1). This causes the water to form a powerful vortex which is directed out through a hole in the centre of the basin. The rotating motion of the vortex causes the turbine to rotate, thus producing mechanical energy which gets converted into electrical energy in the generator.

## II. PAST STUDIES

Various parameters related to water vortex power plants have been investigated by researchers in the past few years. Cerri and Gafner (2010) published a study on the water vortex power plant during their bachelor’s study at FH North-western Switzerland. They calculated an efficiency of 23.5 % for the turbine (7). Mulligan and Casserly (2010) have carried out a study on the design and optimization of water vortex power plant. From their study, they found that the optimum vortex strength is obtained at the basin to orifice diameter of 14% for low head and 18% for high head. They have also found that the vortex height variation and discharge show a linear relationship. According to their study, maximum hydraulic efficiency is obtained when the velocity of the turbine runner is half that of the fluid velocity. An experimental study on the water vortex power plant has been carried out by Mühle et al. in the year 2013 at TU Munich. They conducted experiments on a 1:9 scaled model for water vortex power plant and found that the parameters outlet opening and height of water in the inlet channel had the strongest influence on the efficiency of the water vortex power plant. According to their study, the water vortex power plant is suitable for low flow rates and low flow depths. They found a positive correlation between larger outlet opening and efficiency. Marius-Gheorghe et al. (2013) carried out experimental study on Water Vortex Turbines (WVTs) in which different rotor blades were placed at different heights in a vertical conical channel. They found that the efficiency of the turbines increased up to a certain optimum level and then decreased. Also, they found that the swallowing capacity of the turbine increased when the angle of the conical channel is increased from its tip and the turbine performance was higher at the bottom most position near the drain hole. The performance of the turbine decreased when its position was moved away from the drain hole. Wanchat et al. (2013) have carried out numerical and experimental study on the water vortex power plant. For the experimental study they have constructed a model consisting of a vertical axis turbine with 5 blades. Using a vortex basin of diameter 1 m they have found that the optimum outlet diameter must be in the range of 0.2 m to 0.3 m. They have calculated an efficiency of 30% for the power plant. Bajracharya et al. (2014) have conducted experimental study on the water vortex power plant. They have designed the vortex power plant in the laboratory and conducted various tests using different number of turbine blades. The have carried tests at a wide range of varying speeds of rotation (25 -120 rpm). They confirm investigations of Marius-Gheorghe et al. (2013) regarding the fact, that the best position for the placement of turbine is the bottom most position. Since the value of velocity head increases with the increase in depth, therefore greater efficiency has been found at bottommost position. They also found that increase in the radius of blades decreased the efficiency of turbines due to friction at inner surface of basins. Furthermore, they have found that the vortex strength increases in case of conical basin as compared to the cylindrical basin.

Water vortex turbines suffer from considerably less efficiency. Most of the experimental studies carried out have reported efficiencies from 15 % (15) up to 35% (13). Although few commercial companies operating in the field like Kourispower and Zotlöterer have reported efficiencies up to 85%, these claims must be experimentally validated. This further gives impetus to the need for carrying out more detailed experimental study in the field of water vortex power plants. Until now, to the best of our knowledge, most experimental research in the field of water vortex turbines has been carried using reduced scale models. Several studies have numerically investigated the working of the Water Vortex Power Plant (WVPP).

## III. EXPERIMENTAL SETUP AND METHODOLOGY

In order to capture various complex effects inside the WVPP a 1:1 scale model has been used in the present study. To the best of our knowledge, there has not been any prior study on the topic of WVPP on the scale of this study. Hence this study will help at better understanding the effect of relevant dominant parameters on the performance of WVPP.

The experiments have been carried out in the 1:1 scale laboratory model set up in the Hubert-Engels Laboratory at TU Dresden (Figure 1). The model consists of a 3.8 m high cylindrical water tank (diameter 3 m) which is connected to the spiral shaped vortex basin through the upper water channel. The outlet of the vortex tank is connected via a circular opening to the lower water channel which acts like a tail race channel for discharging water out of the vortex basin. The upper and lower channel has an increased length because of the requirements as an ethohydraulic test site (Müller et al. 2018). The turbine is placed in the centre of the vortex tank. The generator is placed directly above the turbine which is connected to the brake resistor for transmission of generated electrical power.

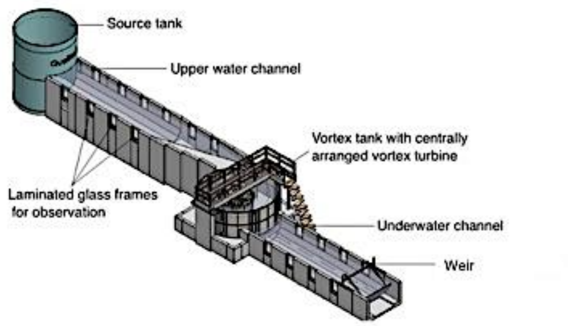


**Figure 1: Construction of the water vortex turbine model. (modified)(14)**

The bottom of the upper and lower water channel as well as the bottom underneath the vortex tank have been concreted on site in the laboratory. At the downstream of the lower water channel a weir has been built whose height can be varied. This helps in regulating the flow in the lower water channel. The turbine has been designed for a maximum discharge of 710 l/s. The design head of the vortex plant is 1.07 m (14). The water which is used for the experiments is stored in two underground deep tanks each with a capacity of 150 $m^3$. Three pumps(each with a capacity of 250 l/s) are used to pump the water from the deep tanks into the model.

## IV. EXPERIMENTAL PROCEDURE

By varying the flow rate, generator settings and outlet height in the WVPP model, a set of tests were carried out to see the influence of various parameters on the performance of vortex turbine. The height of water in the upper and lower channels and in the vortex tank is recorded by means of ultrasonic sensors positioned at different places along the length of the channels. In order to regulate the height of water in the WVPP, wooden logs have been placed at the clap located at the end of downstream channel. A set of tests were carried out for each outlet height from 0 to 0.36m (see Table 1) by varying the discharge from 160 l/s to 700 l/s. For each test the values of output power, turbine rotational speed, height of water in the vortex tank and height of water in the upper and lower channel has been measured. At maximum six wooden logs have been used. “W0” is an abbreviation representing the number of wooden logs used.

| S.No. | Impounded height (m) | Abbreviation used |
|---|---|---|
| 1. | 0 | W0 |
| 2. | 0.06 | WI |
| 3. | 0.12 | WII |
| 4. | 0.18 | WIII |
| 5. | 0.24 | WIV |
| 6. | 0.30 | WV |
| 7. | 0.36 | WVI |

**Table 1: Impounding height and abbreviation used.**

The setting speed of the generator was varied by applying different generator curves. Table 2 shows the summary of the setting for various parameters for different tests.

| Name of the applied generator curve | Power | Setting speed | Air core vortex | Remarks |
|---|---|---|---|---|
| V1 | Grid + Resistor | 27 rpm at 710 l/s | Yes | WI to WVI and flow rates 160 to 700 l/s |
| V1.1 | Resistor | 27 rpm at 710 l/s | Yes | WI to WVI and only selected flow rates |
| V2 | Grid | 24 rpm at 710 l/s | No | WI to WVI and 700 l/s |
| V2.1 | Resistor | 24 rpm at 710 l/s | No | WV and 700 l/s |
| V2.2 | Resistor | 23 rpm at 710 l/s | No | WV and 700 l/s |

**Table 2: Description of Tests carried on the WVPP model**

## V. RESULTS AND DISSCUSSION

While performing the Tests V1 and V1.1 it was found that an air core vortex gets formed under the turbine. Therefore, the setting speed of rotation for the turbine was reduced to 24 rpm for a discharge of 700 l/s. Fig. 3 and 4 shows the images of the air core vortex getting formed under the turbine for two different speeds of rotation of the turbine. It can be seen from the Figures that the vortex is large in size at the speed of 29.9 rpm. As the speed reduces, the air vortex also decreases. The air vortex is non-existent as the speed decreases to 24.3 rpm (Fig. 4). This situation is assumed to be the best operating point for the water vortex power plant. The formation of the air core vortex is very sensible to the boundary conditions: It changes depending on the under-water level and the discharge. As a result, the first analysis test with generator curve V1 has been neglected. The results from Test V1 may not be considered reliable due to large fluctuation in the output power between grid and resistor.

**Figure 3: Air core vortex at a speed of 29.9 rpm and discharge of 700 l/s**

**Figure 4: Air core vortex at a speed of 24.3 rpm and discharge of 700 l/s**

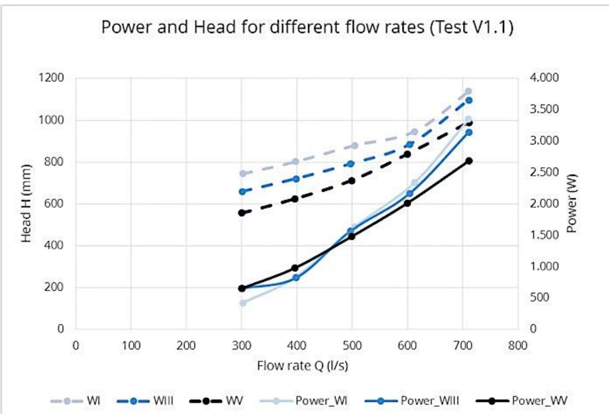


**Figure 5: Measured relationship between Head, Power and Flow Rate**

In Figure 5 it can be seen that head and power increase as expected depending on the flow rate. Equally the effect, that higher head results in higher power output is reliable. If Tests WI and WIII are compared, which differ in the impounding height in 0.12 m, the difference in head is only 0.04 m. Between WIII and WV-Tests the difference in head is even higher with 0.11 m. That means, that the backwater effect is not fully transmitted to the upper channel. In the analyzed tests the theoretical power output has been determined between 6.9 kW and 7.9 kW.

Fig. 6 shows the efficiency and speed relationship for three outlet heights abbreviated as WI, WIII and WV. From Fig. 6 it can be seen that the efficiency increases with the increase in speed of rotation up to a maximum value and then decreases. Mühle et al. (2013) and Dhakal et al. (2017) have also obtained similar curves for the relationship between speed and efficiency of the WVPP.

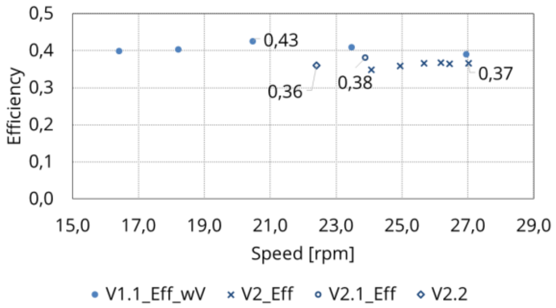


**Figure 6: Speed vs Efficiency relationship for the WVPP model**

Since Test V2 and V2.1 were carried out at a single flow rate of 700 l/s, therefore it was not possible to perform tests at different speeds of rotation. Hence a performance curve could not be obtained for these Tests.

| Number | Name | Wood | Power (kW) | Maximum Efficiency | Flow rate (l/s) | Head (m) | Speed (rpm) |
|---|---|---|---|---|---|---|---|
| 1. | V1.1 | WV | 1.5 | 0.43 | 500 | 0.7 | 20.5 |
| 2. | V2 | WIV | 2.5 | 0.37 | 700 | 0.97 | 25.7 |
| 3. | V2.1 | WV | 2.45 | 0.38 | 700 | 0.92 | 23.9 |
| 4. | V2.2 | WV | 2.24 | 0.36 | 700 | 0.90 | 22,4 |

**Table 3: Comparison of maximum overall efficiencies from various Tests.**

From Table 3, it can be seen, the maximum overall efficiency is 43 % at 500 l/s. For Test V2 the maximum efficiency is 37 % at 700 l/s. Since it was not possible to conduct experiments for Test V2 and V2.1 at lower flow rates, therefore the maximum efficiency for these tests is not known. Another Table (Table 4) is drawn to make a comparison at the same flow rate of 700 l/s and WV between various tests conducted on the WVPP.

| Number | Name | Power (kW) | Efficiency | Flow rate (l/s) | Head (m) | Speed (rpm) |
|---|---|---|---|---|---|---|
| 1. | V1.1 | 2.7 | 0.39 | 700 | 1.0 | 27.0 |
| 2. | V2 | 2.32 | 0.36 | 700 | 0.93 | 24.9 |
| 3. | V2.1 | 2.45 | 0.38 | 700 | 0.92 | 23.9 |
| 4. | V2.2 | 2.24 | 0.36 | 700 | 0.9 | 22.43 |

**Table 4: Comparison of maximum efficiencies for various Tests at flow rate of 700 l/s and WV.**

Table 4 shows that at the same flow rate of 700 l/s and the same under water boundary condition WV, the efficiency is almost similar in the conducted tests. For Test V1.1 the maximum efficiency at the flow rate of 700 l/s and WV is 39 %. For Test V2, the highest efficiency at 700 l/s and WV was 36 %. For Test V2.1, the maximum efficiency was 38 %. Comparing tests V1.1, V2 and V2.1 it can be seen, that the difference between the efficiencies for these Tests is considerably low. The higher efficiency obtained for Test V1.1 (39 %) than Test V2 (36 %) may be due to higher generator speed set for Test V1.1 (27 rpm at 700 l/s).

The power output for Test V2 is greater as compared to Test V2.2, but the efficiency is same. This may be due to higher head and speed of turbine in Test V2 as compared to Test V2.2.

Moreover, for the same head (0.92 m) for Tests V2 and V2.1, the power output for Test V2.1 is higher by about 5% as compared to Test V2. This may be due to greater air core formation in Test V2. This shows that power increases when the air core formation decreases. This is confirmed by the Euler's equation also according to which we get the highest power output when there is no air core formation.

## VI. CONCLUSION

Under the given boundary conditions of flow rate, head and speed of rotation for this study and from all the tests conducted, it was found that the maximum efficiency of the WVPP is 43 % at the flow rate of 500 l/s and head 0.7 m. However, the best efficiency obtained without air vortex formation under the turbine was 38 % at the flow rate of 700 l/s and head 0.92 m. The power obtained was also maximum (2.45 kW) at this efficiency. The efficiency obtained was found to be comparable with the values provided by companies like Ecoligent and GWWK (6). The efficiency was also found to be comparable with the value of efficiency from the study by Mühle et al . (2013).

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