Gravitational water vortex pico hydro power modeling for aquaculture implementation

D W Maulana\textsuperscript{1}, F M Rizwan\textsuperscript{2}, C Mulyana\textsuperscript{2}, F Faizal\textsuperscript{1,2}, C Panatarani\textsuperscript{1,2} and I M Joni\textsuperscript{1,2,*}

\textsuperscript{1}Nanotechnology and Graphene Research Centre, Universitas Padjadjaran, Jl. Raya Bandung-Sumendang KM. 21 Jatinangor, Sumedang 45363, Indonesia.
\textsuperscript{2}Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Jl. Raya Bandung-Sumendang KM. 21 Jatinangor, Sumedang 45363, Indonesia.

*imadejoni@phys.unpad.ac.id

Abstract. Nanotechnology and Graphene Research Centre (PRINT-G) of Universitas Padjadjaran is currently developing fine bubble generator (FBG) technology which is applied for the fisheries sector to process aquaculture wastewater into clean water and as an aerator. In its implementation, adequate energy is needed, but it can be applied with cheaper electricity costs, such as renewable energy sources. In this research, a gravitational water vortex pico hydro power (GWVPHP) plant modeling has been carried out. This system can be used under 2 meters head condition and for small water flow, that is suitable to use in fishing pond locations that do not have high head and limited water. It is known that the velocity of water flow is 0.4 m/s, and the head is 1.6 meters with the height level of the water varying every 5 centimeters increase in the range of 5 to 50 centimeters. As a result, we obtained the minimum potential power of 111.9 Watt and a maximum of 1,558.2 Watt. In modeling, we assumed that we used turbine with 80 percent efficiency, thus we obtained the turbine generation power of 89.6 Watt, and a maximum of 1,246.6 Watt. In addition, the modeling also uses 3 phase AC generators with an efficiency value of 70 percent, so that a minimum generator generation power of 62.7 Watt is obtained, and a maximum of 872.6 Watt is obtained. Control panel also used with an efficiency of 70 percent, so that a minimum power that produced is 43.9 Watt, and a maximum of 610.8 Watt. Fine bubble generator (FBG) that used for aquaculture needs 125 Watt to be functioned. Thus, the power that had generated by the gravitational water vortex pico hydro power (GWVPHP) plant could be supplied the energy needs of fine bubble generator (FBG).

1. Introduction
For aquaculture implementation, especially in Nanotechnology and Graphene Research Centre (PRINT-G) Universitas Padjadjaran, electricity is needed to use fine bubble generator (FBG) in fish ponds. FBG can be used to treat aquaculture wastewater into clean water and aerates water in fish ponds, so it could help increase the productivity of fish farms. On the other hand, FBG not only adequate energy needed, but low cost and sustainable energy also needed. Hydropower is one of the most commonly used renewable sources of electricity, accounting for about 16.6% of the world’s net electricity [1]. Hydropower is suitable to supply electricity for small to large use. Hydropower potential can be categorized in terms of pico (<0.005 MW), micro (<0.1 MW), mini (<1 MW), small (<10 MW), and large (>10 MW hydropower plants) [2]. Hydropower produced electricity depends on the amount of
water flowrate and head condition. Kaplan and Francis turbines were found to be the most suitable for low-head applications. However, their design and manufacture are relatively complicated and expensive [3] and particular suffer from high maintenance costs [4]. The lower position of bearing for the runner is the most frequent cause of failure, and in addition, the generator windings and seals also fail on a regular basis, and leakage of water into the generator can cause issues. Another disadvantage of Kaplan and Francis arrangements is that they require high flow rates to achieve reliable performance efficiency, which trends to render small run-of-river or domestic applications impractical. Gravitational water vortex pico hydro power (GWVPHP) is picked to be a solution to supply aquaculture electricity needs. GWVPHP works on the principle of harnessing hydroelectric power from the high angular velocity experienced in the core of a whirlpool generated in a vortex basin [5]. GWVPHP design is suitable to use in low head and small to medium water flowrate, same as the condition in aquaculture. Its key advantage lies in the high-power densities produced compared with conventional technologies.

2. Methodology
The modeling was solved by COMSOL Multiphysics 5.3a, with the type of physics turbulent flow k-ε (spf) and stationary study. In this modeling, velocity was assumed by 0.4 m/s, while the height of the water surface was varied in the range of 5 to 50 centimeters in each 5 centimeters increase. So, the value of flow rate, head, and power could be defined. Figure 1 shows the scheme of the gravitational water vortex pico hydro power plant, which arranged by canal, basin, pipes, turbine, generator, control panel, ballast, and consument.

![Figure 1. The gravitational water vortex pico hydro power plant scheme.](image)

The turbulent model that used is k-ε (spf). In a k-ε model solved momentum equation using Navier Stokes equation, which is assumed that flow in full turbulence with solved by three equations are turbulence kinetic energy (k), dissipation rate (ε), and gravity (g):

\[
\rho (u \cdot \nabla) k = \nabla \cdot \left[ \mu + \frac{\mu_T}{\sigma_k} \right] \nabla k + \rho_k - \rho \varepsilon \tag{1}
\]

\[
\rho (u \cdot \nabla) \varepsilon = \nabla \cdot \left[ \mu + \frac{\mu_T}{\sigma_\varepsilon} \right] \nabla \varepsilon + \frac{C_\varepsilon}{k} \rho_k - \frac{C_\varepsilon}{k} \rho \varepsilon^2, \quad \varepsilon = \rho \varphi \tag{2}
\]

\[
\rho (u \cdot \nabla) u = \nabla \cdot \left[ -\rho l + (\mu + \mu_T) (\nabla u + (\nabla u)^T) \right] + F + \rho g \tag{3}
\]
The optimization power that produced is divided into potential power ($P$), turbine power generation ($P_t$), generator power generation ($P_g$), and power produced (or power control panel generation, $P_k$). These are the equations:

\[ P = \rho gHQ \]  \hspace{1cm} (4)

\[ P_t = \eta_t P \]  \hspace{1cm} (5)

\[ P_g = \eta_g P_t \]  \hspace{1cm} (6)

\[ P_k = \eta_k P_g \]  \hspace{1cm} (7)

H is head, and Q is water flowrate. The type of turbine that used has an efficiency ($\eta_t$) about 80 percent. Then, 3 phase generator and control panel in this model each has an efficiency of 70 percents ($\eta_g$ and $\eta_k$)

3. Result and Discussion

The canal and basin of GWVPHP were modeled using COMSOL Multiphysics 5.3a, with the variation of the height of water surface (h) affects the water velocity in canal (basin inlet). It is shown respectively in figure 2.

![Figure 2. Velocity magnitude of basin inlet (a) in maximum and (b) in minimum height of water surface.](image)

| Height of Water Surface (cm) | Potential Power (Watt) | Turbine Generation Power (Watt) | Generator Generation Power (Watt) | Production Power (Watt) |
|-----------------------------|------------------------|---------------------------------|-----------------------------------|------------------------|
| 5                           | 112                    | 89.6                            | 62.7                              | 43.9                   |
| 10                          | 233.7                  | 186.9                           | 130.8                             | 91.6                   |
| 15                          | 365.2                  | 292.2                           | 204.5                             | 143.2                  |
| 20                          | 506.4                  | 405.1                           | 283.6                             | 198.5                  |
| 25                          | 657.4                  | 525.9                           | 368.1                             | 257.7                  |
| 30                          | 818.1                  | 654.4                           | 458.1                             | 320.7                  |
| 35                          | 988.5                  | 790.8                           | 553.6                             | 387.5                  |
| 40                          | 1168.6                 | 934.9                           | 654.4                             | 458.1                  |
| 45                          | 1358.5                 | 1086.8                          | 760.8                             | 532.6                  |
| 50                          | 1558.2                 | 1246.6                          | 872.6                             | 610.8                  |
When h in maximum condition at 50 centimeters, water velocity in basin inlet obtained 1.05 m/s. While h in minimum at 5 centimeters, water velocity in basin inlet obtained 0.51 m/s. Water velocity in h minimum had turbulence in 2.5 meters coordinates of canal length, so the velocity had increased not significant.

The variation of water surface (h) is also affects the amount of flowrate (Q), with larger amount of h will produced large amount of Q, and vice versa. Flowrate is defined by $Q = A \times v$, whereas $A$ is water surface area, and $v$ is water velocity. Thus, large amount of flowrate (Q) and head (H) affects to amount power that can be produced as shown in table 1.

\[ \text{Figure 3. The effect of variation of water surface height to amount of power that can be generated.} \]

As shown at figure 3, the amount energy that can be generated is decreased because of energy loss in each part. Potential energy that produced is 1558.2 Watt, then propeller turbine with an efficiency of 80 percent generated power of 1246.6 Watt. Generator with 70 percent efficiency generated 872.6 Watt power. Final result, control panel with an efficiency of 70 percent produce electricity 610.8 Watt.

4. Conclusion
Gravitational water vortex pico hydro power is applicable for aquaculture implementation with low head and small flowrate. The minimum electricity that can be produced by GWVHP is 43.9 Watt and maximum is 610.8 Watt. So that amount of electricity can be used as energy supply for aquaculture, especially to use fine bubble generator (FBG).

Acknowledgments
The authors would like to acknowledge WCR (World Class Research) Research Scheme, Ministry of Research, Technology, and Higher Education of the Republic of Indonesia for funding this research work.
References

[1] REN21 2015 Renewables 2015 global status report (Paris: REN21 Secretariat)
[2] Hoes O A C, Meijer L J J, Van der Ent R J and Van de Giesen N C 2017 PLoS ONE 12 e0171844
[3] Demetriades G M, Williams A A and Smith N P A 1995 The use of propeller turbines in low head stand alone micro hydroelectric power generation units Int J Ambient Energy 16 162
[4] Engelke W R, Rakwichian W and Ketjoy N 2006 Int J Renew Energy 1 55
[5] Timilsina A B, Mulligan S and Bajracharya T R 2018 Nature 20,1737