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Numerical analysis of the inlet channel and basin geometries for vortex generation in a gravitational water vortex power plant

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Research problem

Recently, the utilization of low-head hydroelectric technologies has received a great attention for the expansion of distributed power systems into isolated regions that are difficult to be connected to the electrical grid, especially in developing countries. The use of gravitational vortex hydropower systems can be a renewable and suitable option to expand the electricity access and promote development in these remote regions, which are concomitantly rich in hydric resources, due to these systems can operate with low head without the requirement of a large reservoir and installation area.

In this study, the performance of the inlet channel and the basin of a gravitational water vortex turbine (GWVT) was investigated. Two inlet channels and two basin geometries were numerically analysed in Ansys Fluent software. The velocity and vortex height were calculated and compared for each setting. It was found that the inlet channel with conical basin tended to produce a more symmetric vortex in comparison with that one generated by the cylindrical geometry. Additionally, the conical basin maximized the flow velocity on the water surface area.

Keywords: Gravitational vortex, low-head hydropower, CFD, cylindrical and conical basin

Material and methods

Channel and basin configuration

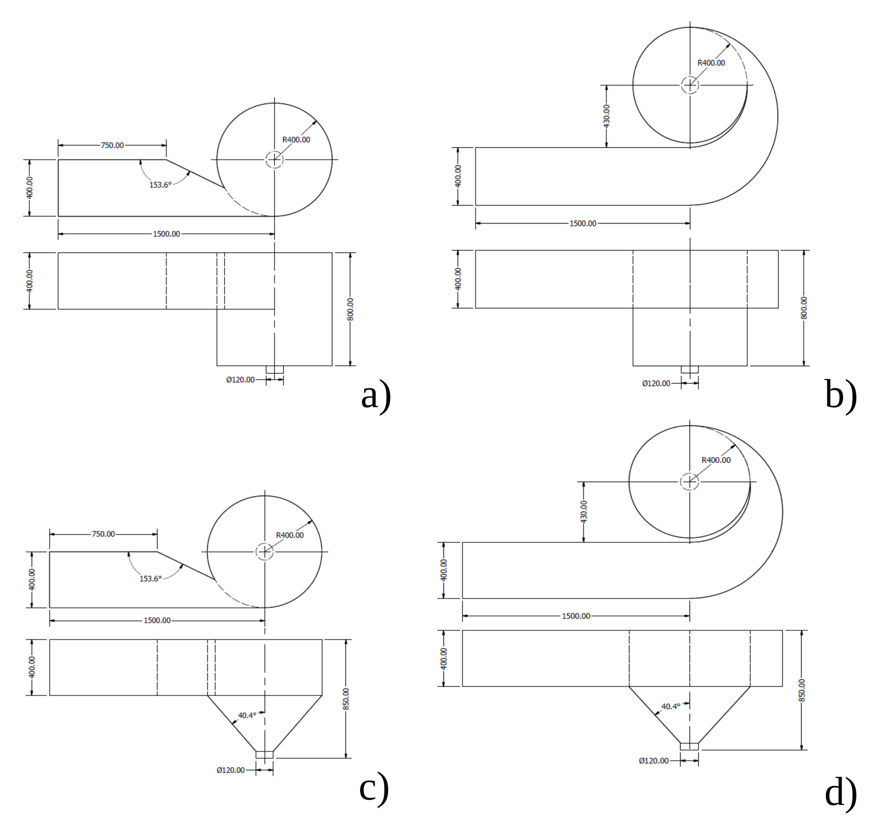

Figure 1. Geometrical configuration of the inlet channel and basin. a) Tangential inlet with cylindrical basin, b) wrap-around inlet with cylindrical basin, c) tangential inlet with conical basin, d) wrap-around inlet with conical basin.

Objective

In the literature, a limited number of studies focused on the design and manufacture of the vortex turbine is reported. Furthermore, to the authors' knowledge, no researches based on the assessment of the influence of the wrap-around inlet on the mentioned turbine geometrical configuration have been reported.

Under this scenario, this work is aiming at determining an optimal inlet channel and basin for vortex generation using Computational Fluid Dynamics (CFD) numerical models developed in Ansys Fluent software (Figure 1).

Table 1. Parameters involved in the CFD analysis.

Parameter	Description
Flow analysis	Unsteady
Temporary step	0,1 s
Total simulation time	300 s
Fluid	Water at 25 °C
Turbulence model	$k-\varepsilon$
Inlet	Velocity inlet (0,1 m/s)
Outlet	Pressure outlet
Upper surface	Atmospheric pressure

ANSYS
CFD package Ansys Fluent software

Figure 2 represents the changes in the output mass flow as a function of the simulation time. For the models with wrap-around inlet, the time required for the mass flow to be stabilized (maintaining a constant flow in the gravitational vortex of 16 kg/s) was observed to be less than that obtained using models with tangential inlet.

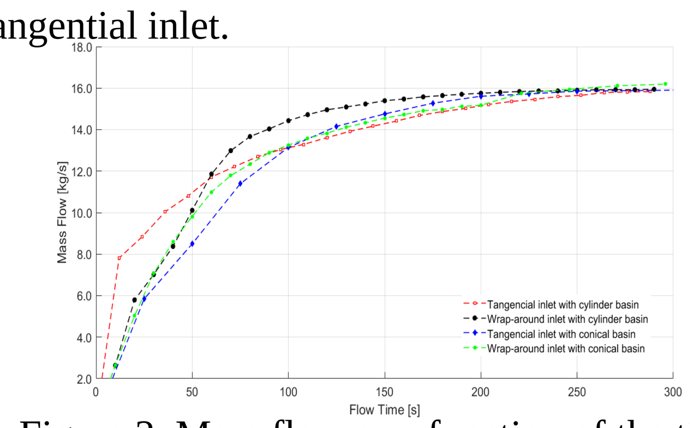

Figure 2. Mass flow as a function of the time.

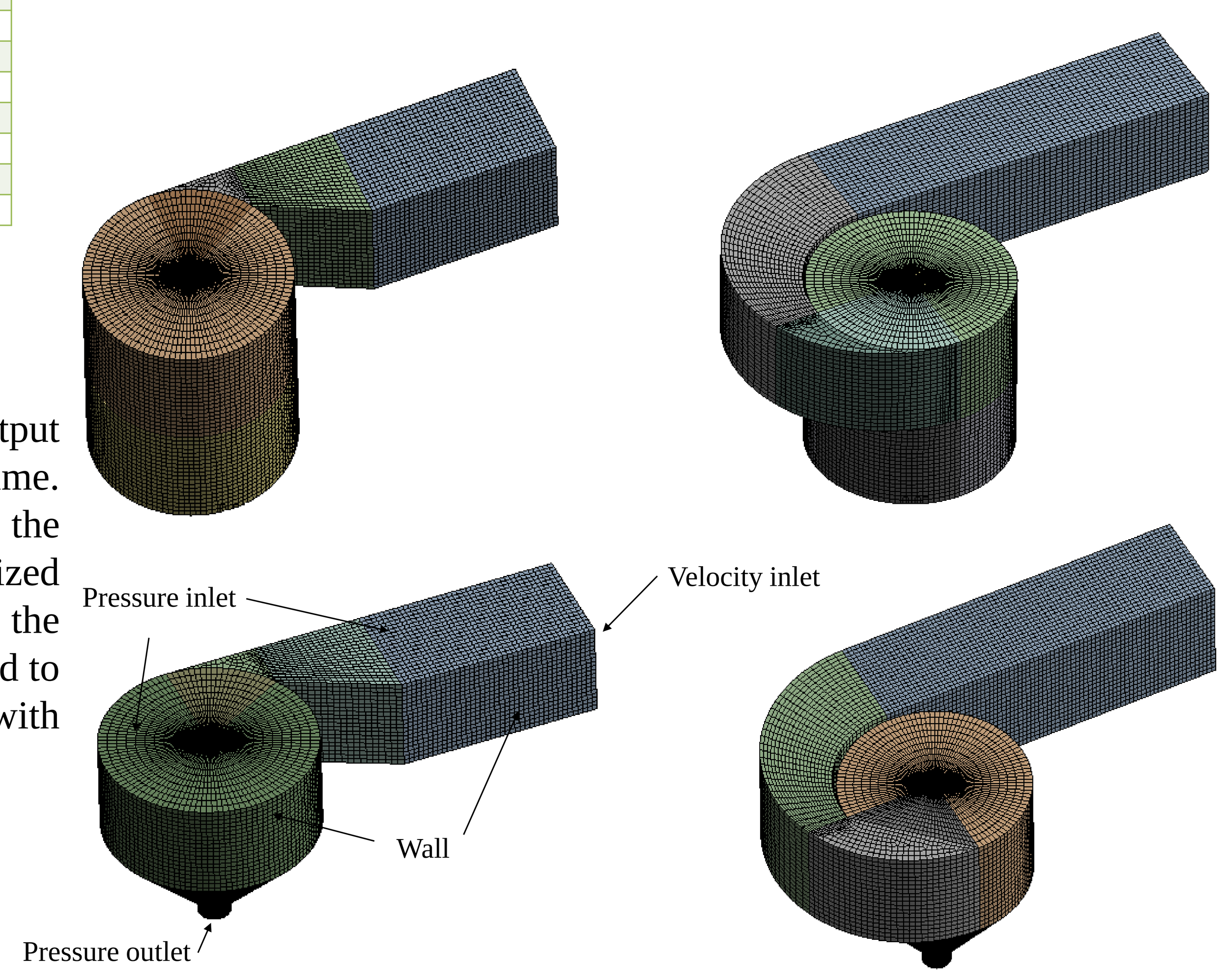

Figure 3. Computational domain of the inlet channel and basin. a) Tangential inlet with cylindrical basin, b) surrounding inlet with cylindrical basin, c) tangential inlet with conical basin, d) surrounding inlet with conical basin.

Results and discussion

It is noteworthy that depending on the design of the GWVT basin, the vortex profiles created are different. Figure shows the volume fraction of water and air at 300 s. Water in Figure is represented by red color, while air, by blue color. Figure 4 illustrates the vortices, which are perfectly formed. The vortex of model 4 (i.e., the model with wrap-around inlet and conical basin) can be observed to be more symmetrical and higher than those ones obtained with the other evaluated models.

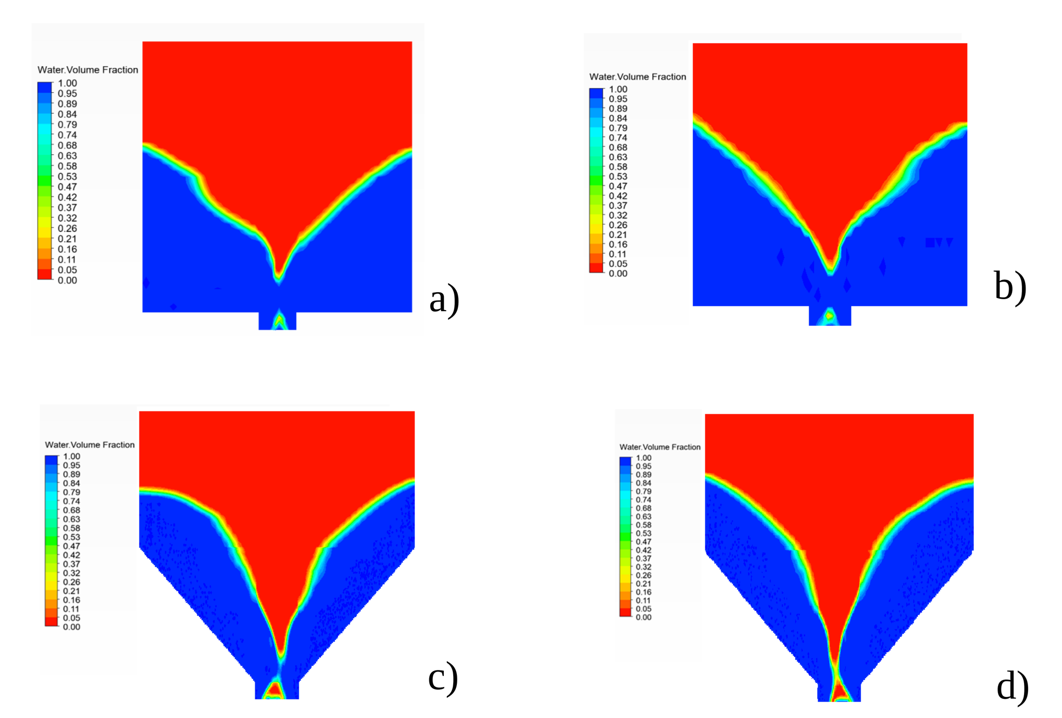

Figure 4. Water volume fraction at 300 s. a) Tangential inlet with cylindrical basin, b) wrap-around inlet with cylindrical basin, c) tangential inlet with conical basin, d) wrap-around inlet with conical basin.

Figure 5 shows that the conical basin in both inlet geometries produces a symmetric and stable vortex. It is important to note that a symmetric vortex causes a radial force of smaller magnitude. Additionally, radial steering forces are responsible for creating moments of flexion in the shaft of the turbine, which reduce its efficiency and durability

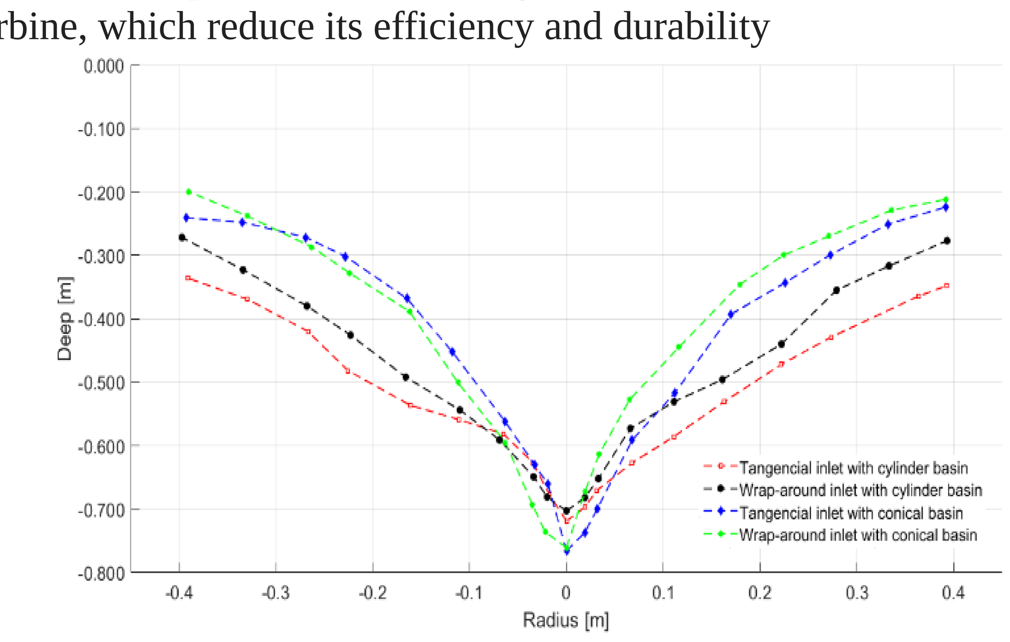

Figure 5. Vortex profile for several basins and inlets.

In general terms, from the flow simulation, the average velocity in the conical basin was higher than that achieved in the cylindrical basin under similar conditions of head and discharge. This can be explained as a consequence of the inflow area decrease in the conical basin. Velocity increases, thereby, maintaining a constant flow rate. From the results obtained, the same turbine should be expected to extract much more power from the conical basin than from the cylindrical one since the power output is influenced by the vortex height and the water flow rate.

The tangential velocity distribution along the radial direction is represented in Figure 6. It was found that, from the radius of the vortex core, the tangential velocity increases to a maximum value, which is reached at a radius value approximately equal to 50% of the basin radius. Furthermore, the wrap-around the inlet with conical basin configuration was observed to provide the largest values for tangential velocities of 1.55 m/s when the radius was 0.22 m.

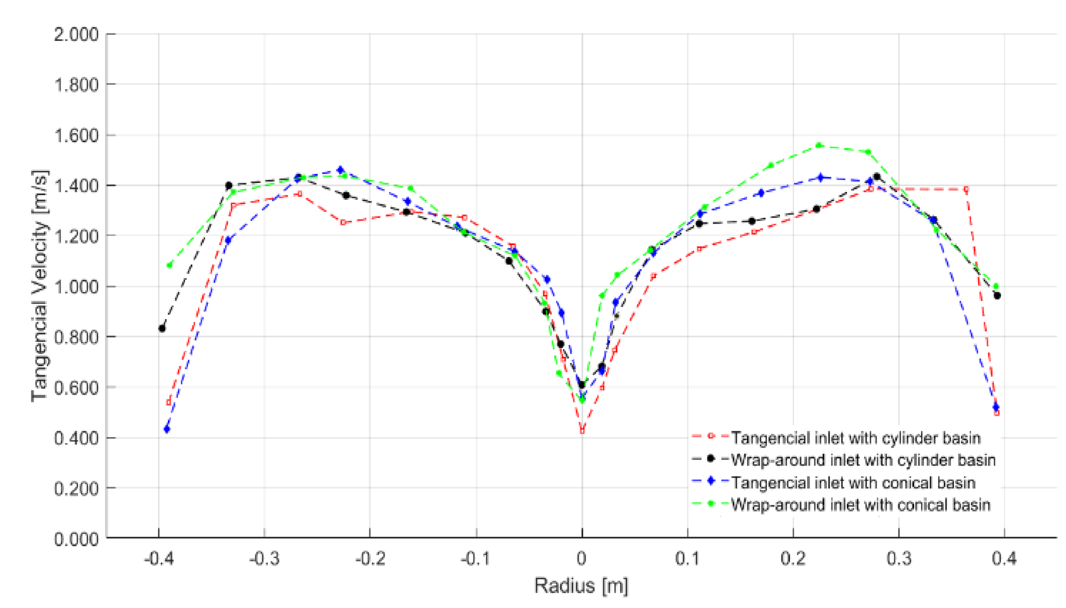

Figure 6. Tangential velocity distribution along the radial direction for several basins and inlets.

The computational study suggests that the conical basin is much better than the cylindrical one for the provided head and discharge. It is highlighted that several researchers also conducted a number of tests on the basin. They found that the vortex strength in the conical basin was stronger than in the cylindrical basin.

Conclusion

Gravitational water vortex power plants can be a suitable option for rural electrification. This system is an emerging technology in the context of low head hydropower plants. The channel design and basin are important parameters for effective vortex generation; therefore, CFD analyses were conducted on the inlet channel (tangential or wrap-around inlet) and the basin (cylindrical or conical) of a GWVT in order to discern the effect of the combination of geometrical configuration of these components. Four configuration with diameter and height of the basin of 0.8 m were modelled. The performances of the models based on the tangential velocity and the quality of the vortex produced were studied. It was found that a conical basin with an orifice at the bottom centre was the most suitable configuration to create larger kinetic energy in the vortex. Additionally, it was observed that model 4, which was defined by a wrap-around inlet and a conical basin, was the most suitable one since it provided a higher and more uniform velocity compared to the other models evaluated.

Furthermore, from the result analysis, it was evidenced that model 4 configuration provided the maximum tangential velocity, which is a relevant component to drive the turbine blade. This velocity was proportional to the power output. On the other hand, it is important to note that knowing the location of the highest velocity allow to identify the optimum point of a rotor installation, since a greater extraction of energy from the flow is possible at this point.

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