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Runner optimal position in a gravitational water vortex hydraulic turbine with a spiral inlet channel and a conical basin

Velásquez García L[1], Rubio-Clemente A[1], Chica E[1]
[1] Grupo de Investigación Energía Alternativa, Facultad de Ingeniería, Universidad de Antioquia UdeA, Calle 70, No. 52-21, Medellín, Colombia.

Phone/Fax number: +57 2195547, e-mail: edwin.chica@udea.edu.co

Research problem

A gravitational water vortex hydraulic turbine (GWVHT) is a low head hydropower technology with a vertical runner used for extracting energy from the water vortex. To determine the runner optimal position (h) for the hydropower plant efficiency to be increased, a runner in three different positions was compared using computational fluid dynamics (CFD). The position of the runner was a function of the basin height (H). The maximum efficiency (44.15%) was established when the runner was located at 60% of H. The angular velocity associated with the maximum efficiency was 14 rad/s.

Keywords: Gravitational water vortex hydraulic turbine, runner, efficiency, hydropower

Material and methods

Objetive

Considering that a limited number of studies focused on the design and manufacture of the vortex turbine is reported, and that no researches based on the assessment of the influence of the positions of the runner on the mentioned turbine geometrical configuration have been reported, this work is aiming at determining the optimal position of the runner in the circulation chamber using Computational Fluid Dynamics (CFD) numerical models developed in Ansys Fluent software. The geometry used was a turbine with a spiral inlet channel and a conical basin which, is show in Figure 1.

In this regard, the GWVHT efficiency is expected to be rose with this work.

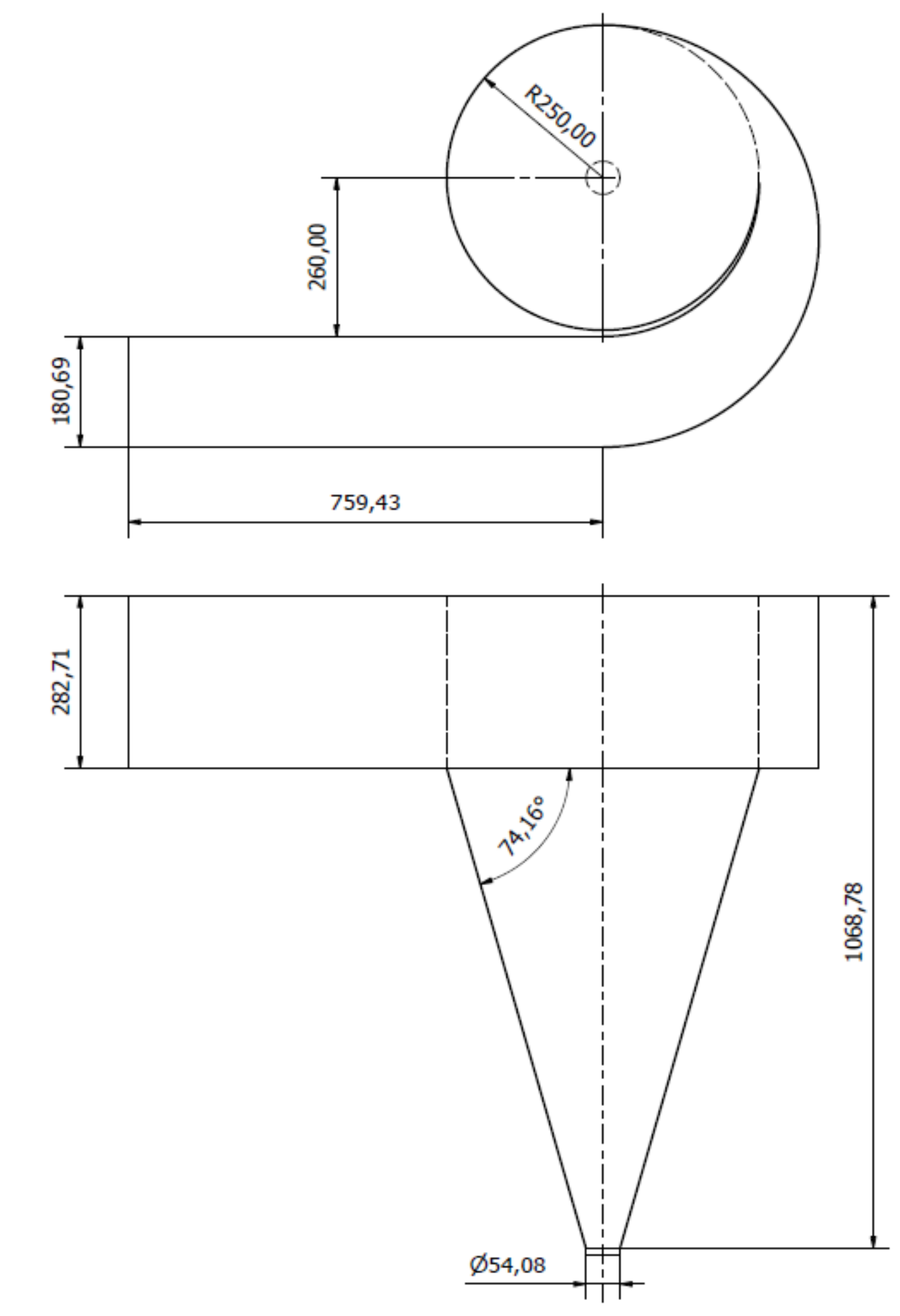
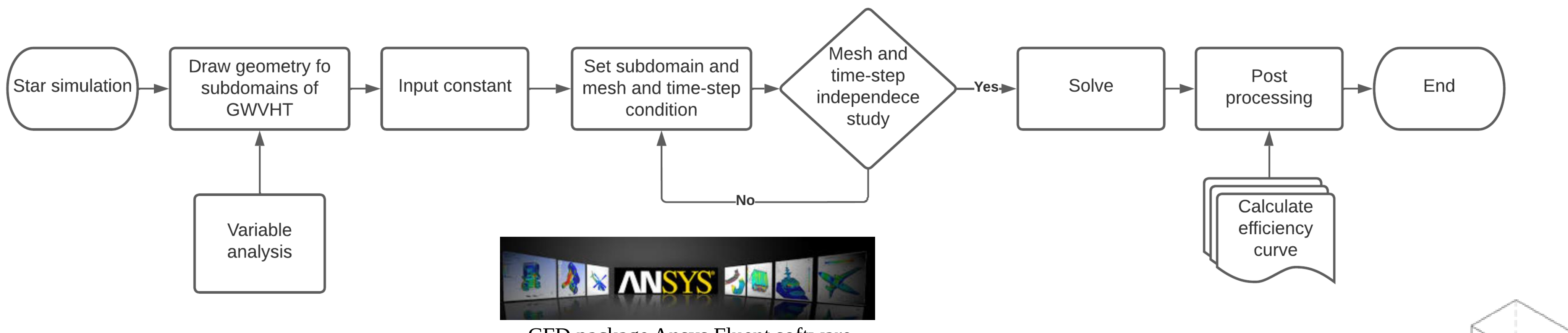
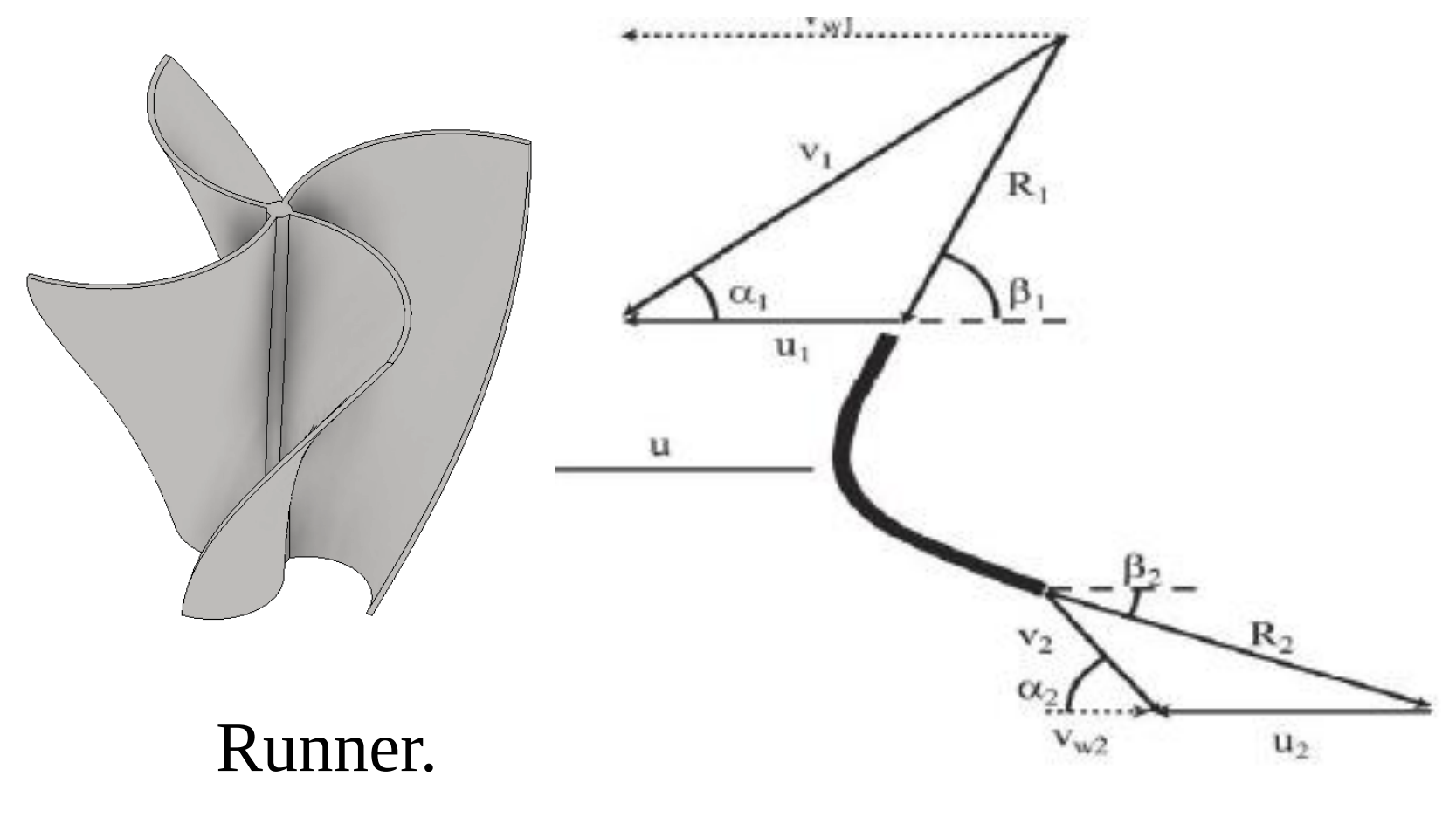


Fig. 1. General view of the GWVHT.

The flowchart of study

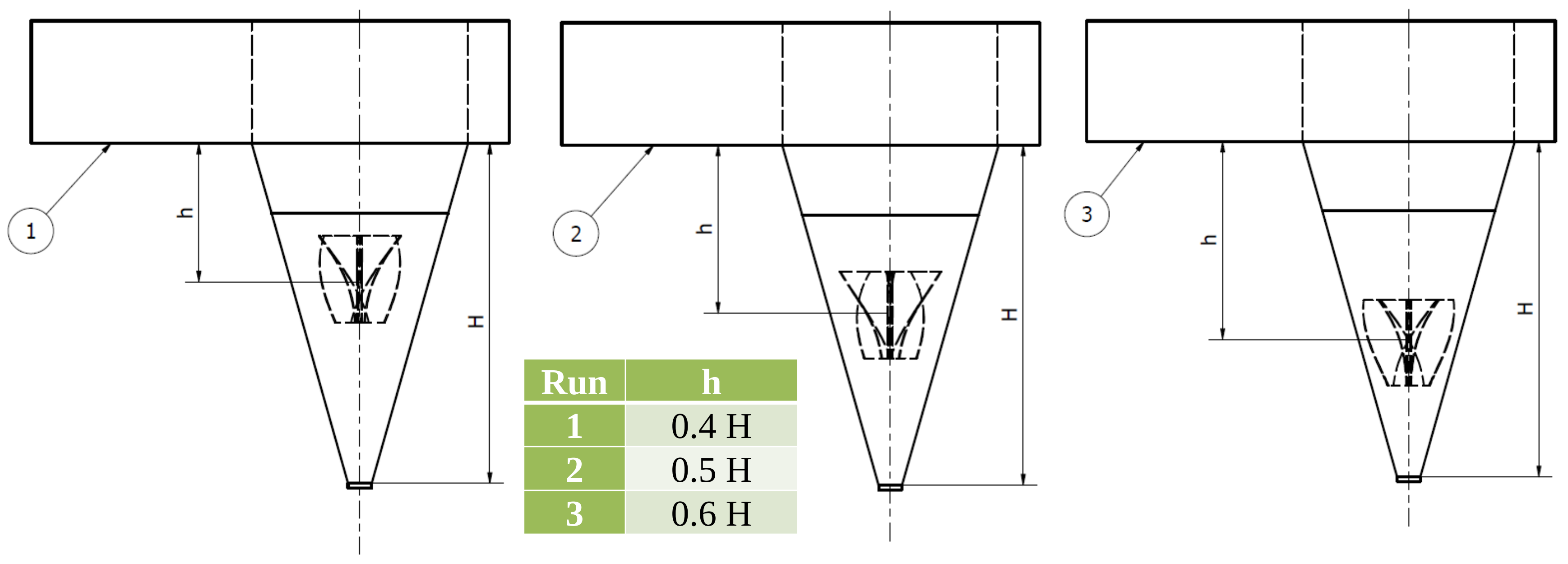

Star simulation
Draw geometry fo subdomains of GWVHT
Input constant
Set subdomain and mesh and time-step condition
Mesh and time-step independece study
Yes
Solve
Post processing
End
No
Variable analysis
Calculate efficiency curve

CFD package Ansys Fluent software



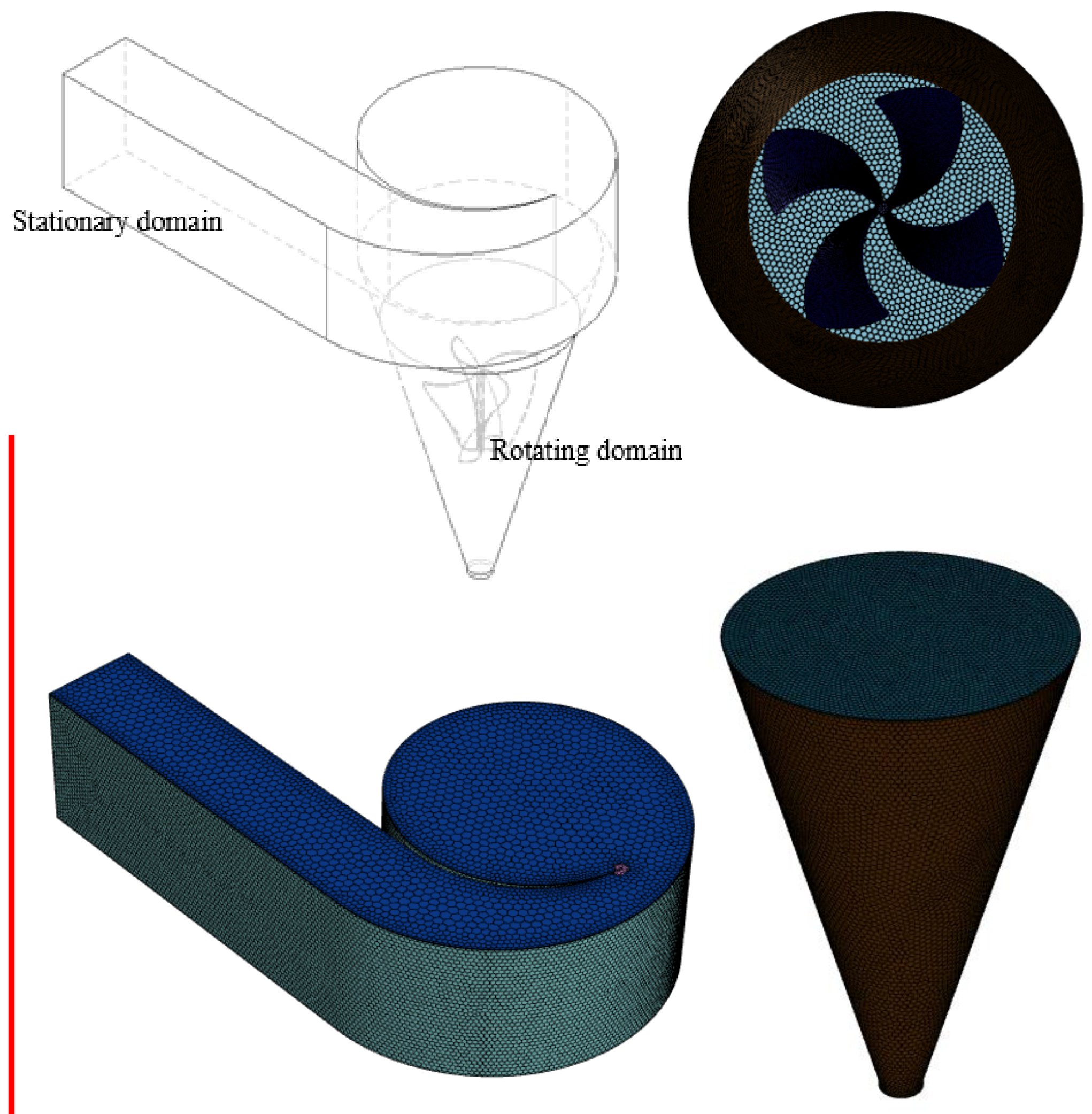
Runner.

Symbol	Variable	Value
α_1	Blade inlet angle (°)	16.00
α_2	Blade outlet angle (°)	90.00
β_1	Water inlet angle (°)	40.00
β_2	Water outlet angle (°)	85.00
λ	Helical pitch angle (°)	85.80
L	Blade length (mm)	200
n	Number of blades	4.00
Ds	Top diameter	191.10
Db	Bottom diameter	115.73



Run	h
1	0.4 H
2	0.5 H
3	0.6 H

Fig. 2. The geometrical configuration used in this study and its dimensions. Different positions of the runner



	Mesh type and GCI	Number of elements	Δt [s]
1	Coarse	524,025	0.005
2	Medium	870,064	0.0025
3	Fine	2,036,661	0.00125
	GCI	0.990	1.002
The control variable used in these independence tests was the circulation			

Figure 3. Computational domain of the inlet channel and basin. Surrounding inlet with a conical basin.

Results and discussion

Figure 4 illustrates the variations in the output mass flow as a function of the time The time needed for the stabilization of the mass flow (constant flow of 3 kg/s) was observed to be close to 30 s for all the analysed models.

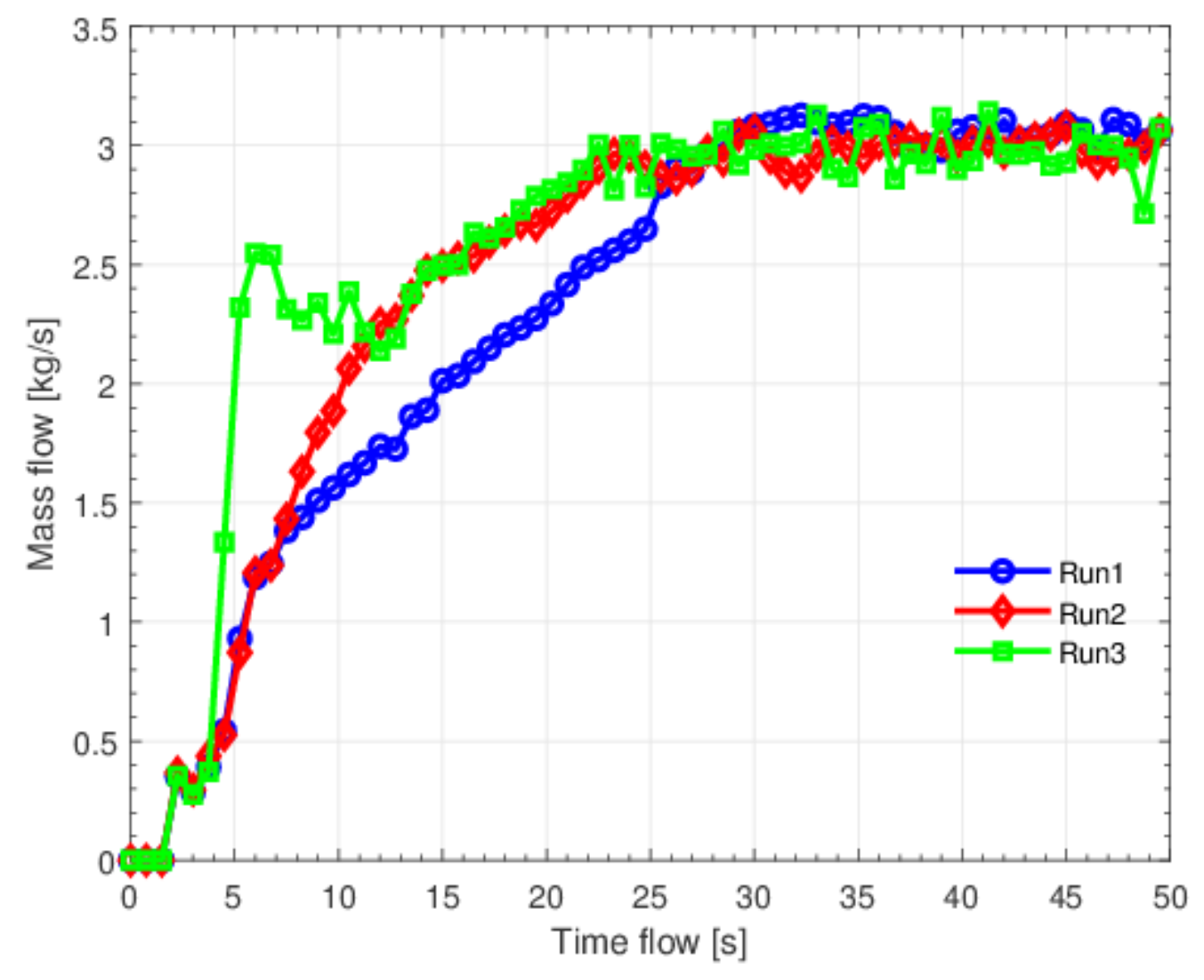


Fig. 4. Mass flow vs. time flow.

Figure 5 shows the efficiency of the model as a function of the angular velocity. The efficiency was calculated using the following equation.

$$\eta = \frac{T\omega}{\rho g h Q}$$

where ρ and g refers to the density and gravity, which were set at 998.2 kg/m^3 and 9.81 m^2/s, respectively. In turn, h stands for the water head (m) and Q is the flow rate, which was set at 0.003 m^3/s. In turn, the values of the torque (T) and the angular velocity (ω) were taken from numerical results.

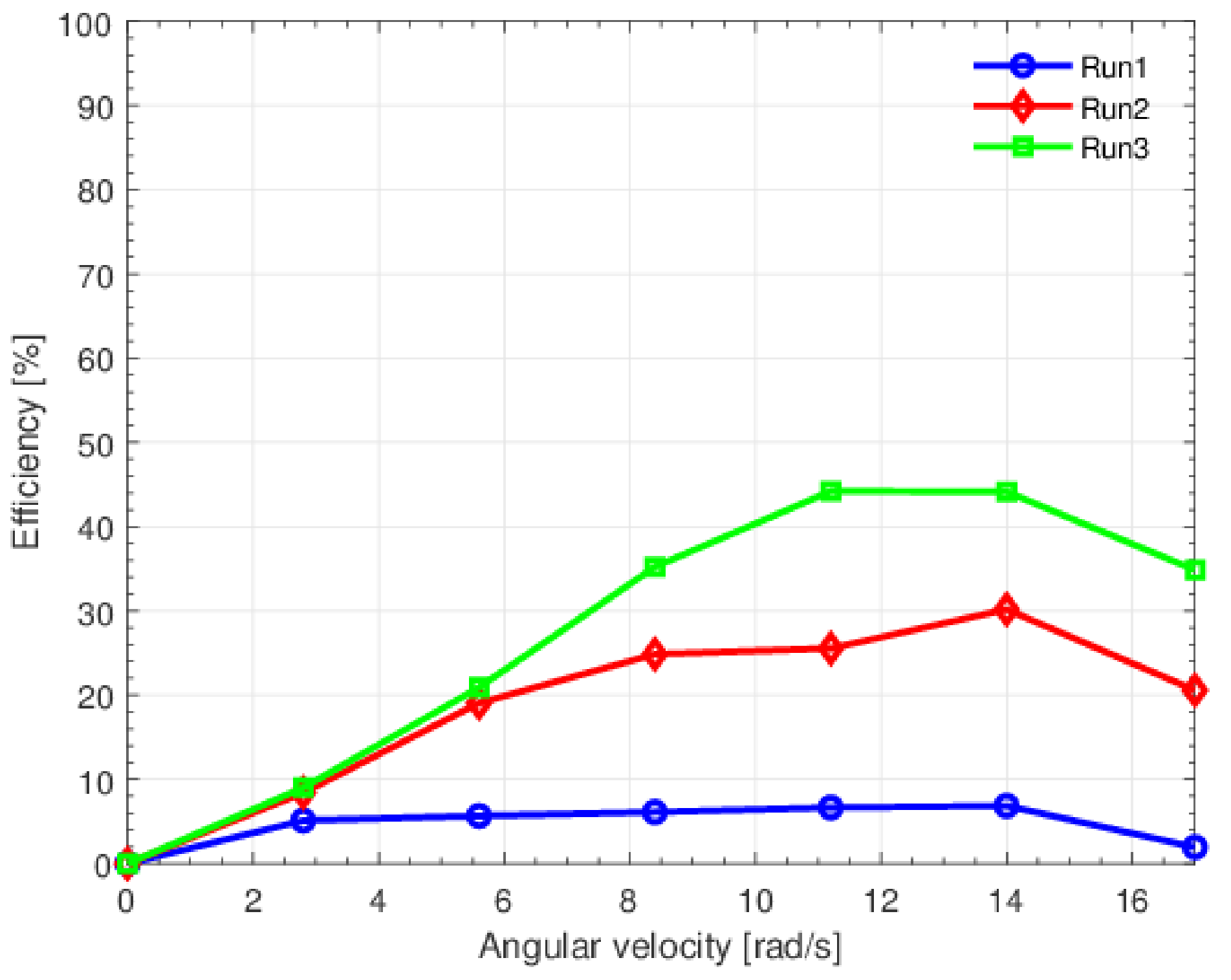


Fig. 5. Efficiency vs. angular velocity.

From Figure 5, run 3 (h=0.6H) has a maximum efficiency of 44.15%. Runs 1 (h=0.4H) and 2 (h=0.5H) have maximum efficiencies values of 6.86 and 30.18%, respectively. The efficiency of the turbine increases as ω is increased and becomes maximal at a ω close to 14 rad/s. Afterwards, the efficiency starts to drop.

According to the characteristics of the vortex, the highest ω will be reached near the exit hole. Therefore, the closer the rotor will be installed to the exit hole, the higher the energy will be available for extraction. Changes of 10% in the location of the runner implied efficiency changes between 13 and 24% for the same runner.

Conclusion

GWVHTs constitute a low head hydropower technology. The requirements for their implementation are lower than those of conventional turbines, since no major civil works are needed, the electricity produced by this technology can be considered renewable and have slight negative environmental impacts associated.

According to the numerical results obtained in this work, the maximum efficiency (44.15%) was established when the runner was located at 60% of the basin height. An experimental verification of the optimal model will be necessary to validate the numerical results. For future works, further numerical and experimental studies should be conducted to establish the optimal runner design for GWVHT, including not only the position of the rotor in the basin but also the number of blades, the inlet and the outlet angles, as well as the helical pitch angle and the rotor diameters and height.

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