

Editorial

Special Issue on “CFD Modelling and Simulation of Water Turbines”

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Climate change and the energy crisis are two main problems that humanity is currently facing and that require immediate action. The global average surface temperature has been increasing over the last few decades, and this does not seem to be changing in the coming years [1]. In addition, the increase in CO₂ emissions will be more than 1 billion tons in 2022 despite the incremental increase in the use of renewable energy technologies around the world, including electric vehicles [2]. One of the solutions that has been proposed to mitigate these problems is related to the energy transition from conventional (non-renewable) to renewable energy sources and the intense use of highly efficient technologies for this purpose. It is known that the most common sources for renewable energy are: solar energy, wind energy, geothermal energy, bioenergy, water (hydropower and hydrokinetics) and ocean energy. Hydropower (including hydrokinetics) and ocean energy are of interest in this Special Issue due to their high percentage of contribution to the total amount of energy generation in the world and higher growth in comparison with other renewable energy sources. Furthermore, hydropower energy generates low emissions (between solar photovoltaic and wind energies) and low costs in comparison to wind and solar energies. Some important facts that corroborate these statements include: In 2010, Tomabeche reported that out of the maximum usable hydropower energy (0.059 ZJ/year), only 0.001 ZJ/year was generated, which is in comparison to wind energy with a potential estimated to be 0.7 ZJ/year, but only 0.00038 ZJ/year was actually generated [3]. In 2019, 3.6% out of the 11.2% of renewable energy that was consumed in the world was generated with hydropower [2]. In 2020, 29% of the energy that was generated globally was from renewable sources, and out of this, 16.8% was generated from hydropower [4]; in addition, the global installed capacity of hydropower grew 1.6%, reaching 1330 GW [5].

Large, conventional hydropower generation plants (greater than 10 MW) majorly contribute to the total installed capacity. These plants require a large dam that typically impacts the physical characteristics of a river and has important biological (ecosystems and river habitat) and social (communities that live on the river shores) impacts. Small hydropower plants or SHPs (less than 10 MW) have fewer environmental impacts than large hydropower plants and are less expensive despite still requiring a dam. The installed capacity of SHPs in the world grew from 71 GW to 78 GW from 2013 to 2019 [6]. On the other hand, unconventional hydropower generation does not require a dam construction and could use the kinetic energy available in water currents such as rivers, waves and tides. Examples of these kinds of hydropower generation are based on hydrokinetic and ocean energy, which are in different stages of development but both have had very interesting growth in recent years. Independent of the type of hydropower generation, the main common device that transforms the kinetic energy available in the water to mechanical energy is the *turbine*, which is the focus of this Special Issue.

The design and performance analysis of a water turbine have been historically carried out with low-order models and physical modelling. In recent decades, the use of simulation tools such as computational fluid dynamics (CFD) have significantly increased up to the



Citation: Lain, S.; Lopez Mejia, O.D. Special Issue on “CFD Modelling and Simulation of Water Turbines”.

Processes **2022**, *10*, 2410.

<https://doi.org/10.3390/pr10112410>

Received: 7 November 2022

Accepted: 13 November 2022

Published: 15 November 2022

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point that, in recent years, physical modelling is no longer used. All the contributions to the present Special Issue are related to the use of different kinds of models and simulation tools applied to water turbines in different contexts. The contributions to this Special Issue can be organized into three main topics:

1. Pump-turbine modelling and simulation [7–9].
2. Modelling and simulation of horizontal- and vertical-axis turbines for hydrokinetic applications [10–14].
3. Modelling of hydropower plants [15,16].

For the first topic, three contributions are related to the use of CFD in the simulation of turbines working as pumps. One of the new trends in hydropower is energy storage (pumped-storage hydropower or PSH); for this purpose, the turbine must work as a pump (typically overnight or in low-energy-demanding time-frames). For this strategy to be considered renewable, extensive research and development must be conducted to understand the performance analysis of the turbine working as a pump. For example, Deng et al. performed a CFD simulation of a model turbine as a pump in order to quantify the energy losses and the entropy generation [7]. Despite CFD simulations assuming that the problem is isothermal, entropy generation can be computed for the viscous dissipation as a postprocess. The proposed analysis is important in order to improve the new designs of pump-turbines with the objective of minimizing the entropy generation and the energy losses for PSH to be feasible. On the other hand, Li et al. [8] investigated the effects of the change in the guide vane airfoil on the flow characteristics in the draft tube of a water pump-turbine. The CFD numerical simulations show that the proposed movable guide vane is able to improve the energy recovery of the draft tube, reducing the vibrations' intensity and enhancing the turbine's stable operation. Moreover, Peng et al. [9] developed an integrated optimization design method of multiphase pumps from both hydrodynamic and structural points of view. Their method was applied to increase the efficiency of a pump, obtaining an enhancement of around 1% with regard to the original model; this numerical conclusion was validated against the experimental tests, allowing them to conclude that the proposed integrated design–meshing–numerical methodology is effective.

A great number of contributions cover the second topic, which is highly related to the development of unconventional hydropower energy. All of these contributions use CFD in different problems, ranging from vertical-axis turbines to horizontal-axis turbines, but all have the common characteristic of the inclusion of more details (either geometrical or physical) in the simulation. For example, Niebuhr et al. proposed a simplified model for the calculation of a small horizontal-axis turbine that includes backwater effects [10]. The model uses the data generated from CFD simulations that include not only the presence of the walls (channel flow), but also the free surface using a multiphase model. The result is a simple model that can be used for the engineering prediction of backwater effects without the need for complex simulations.

The effects of considering the free surface and support structure on the performance of a horizontal-axis water turbine were considered in [11]. The CFD computations clearly show that for shallow immersion, the presence of the free surface induces a reduction in the power coefficient, as well as it being a constraint for the wake developing, which consequently, recovers at a slower rate than in free-flow conditions, a fact that must be taken into account in the design stage of farms based on hydrokinetic turbines. On the other hand, in order to make progress in the optimization of hydraulic, marine, tidal and hydrokinetic turbines, dynamic mesh models have to be used in CFD computations to deal with the complex turbulent flow developing around such turbines. Therefore, the study performed in [12] compares the performance of the standard sliding mesh and the newer overset (chimera) mesh techniques in a vertical-axis water turbine. Advantages and disadvantages of both methodologies are clearly illustrated and thoroughly discussed. Such results are useful to establish best practice guidelines for CFD simulations of this kind of system.

Xiong et al. [13] investigated the hydrodynamic performance enhancement of a hydrofoil when a flapping motion is added to its trailing edge. Such an idea was bio-inspired by examining the flapping movement of a whale tail fin. The authors made CFD simulations as well as particle image velocimetry (PIV) experiments, obtaining a good agreement between them. As a result, the hydrofoil with a clockwise flap presents a better hydrodynamic performance than the basic hydrofoil for small angles of attack, and the counter-clockwise flap increases the critical stall angle, improving the hydrofoil's navigation stability. Finally, it was concluded that adding a short flap to the original hydrofoil improves its performance; moreover, it can be applied to various operating conditions by adjusting the angle of the flap.

Li et al. performed CFD simulations of a tubular turbine (axial-flow) prototype using different clearances or gaps between the blade tip and the shroud [14]. It is important to mention that these gaps are in the order of 5 mm to 20 mm, which is very small in comparison to the runner diameter, which is 7.5 m. This is a very challenging aspect of the CFD simulations since the mesh should be fine enough to correctly capture the details of the flow in the gap. Numerical results show that the size of the gap has an important impact on the axial momentum and the leakage flow, which, in the end, have a great influence on the performance and efficiency of the turbine.

Finally, two contributions are related to the modelling of hydropower plants. At this level, high-order models such as CFD are not practical due to the high computational cost. Saeed et al. proposed a low-order model to identify the fault occurrence in a hydropower plant, which consists of three ponds, a surge tank and the turbine [15]. The dynamic model has the capability to predict the water level in the ponds and the surge tank, as well as the total output power of the turbine. The dynamic model is then coupled with a controller and a fault diagnosis model. Low-order models such as the one proposed in this contribution are useful for the next generation of smart grids based on different types of renewable energy, including conventional and unconventional hydropower. The contribution of Yoosefdoost and Lubitz [16] deals with nonstandard hydropower plants based on Archimedean screw generators. These machines possess several advantages, such as being fish friendly, operating under a wide range of flow heads and generating power from any flow, even wastewater. These authors propose a simple method for estimating the number and geometry of such devices considering installation site properties, river flow characteristics and technical issues. The introduced methodology can be applied to easily evaluate the potential of green and renewable energy generation based on the Archimedes screw.

In general, all the contributions of this Special Issue demonstrate the importance of modelling and simulation in hydropower generation. This new generation of models and simulations will play a major role in the global energy transition and energy crisis, and, of course, in the mitigation of climate change. As the design of turbines relies more on modelling and simulation, researchers and engineers must provide reliable simulation methods and tools. It is important to mention the role that CFD currently plays in the design of water turbines, as its use and implementation is very common in the hydropower industry. Despite this, CFD still has a long way to go in simulating specific details of water turbines such as, for instance, in the simulation of turbines used for unconventional hydropower generation, in the inclusion of geometrical and physical details, and in the correct computation of performance and energy losses.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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