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Design of a recirculating water channel for the development of a hydrokinetic turbine

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Research problem

There is a lack of detailed information on the design and construction of experimental facilities for hydraulic turbines. This study aims to fill this gap by providing a thorough account of the design process, equipment selection, and construction methodology of a specialized water channel for hydraulic turbine experimentation. Additionally, it elucidates the measurement systems' roles and outlines procedures for turbine characterization to plot its performance curve, crucial for understanding efficiency and behavior across operational conditions..

Keywords: renewable energy, recirculating water channel, hydrokinetic turbine, experimental test methodology.

Objective

The aim of this work is to present the development of a recirculating water channel that has been specifically designed for the purpose of studying hydrokinetic turbine. The facility allows for the testing of several geometric configurations and design parameters, which are essential for optimizing the performance of these turbines. The installation is designed to create a controlled environment in which the behaviour of the turbine can be observed and manipulated under different operating conditions.

Designing a water recirculation system for hydrokinetic turbine testing involves several key steps. Firstly, requirements and constraints must be defined, including operational parameters and safety measures. Secondly, the pumping system needs to be designed, considering the required flow rate and selecting appropriate components such as pumps and pipes. Thirdly, the test channel's dimensions must be determined, ensuring realistic flow conditions and compatibility with turbine models. Finally, a control and monitoring system should be established, incorporating instrumentation for measurement and real-time data monitoring..

The design of the water recirculation system for hydrokinetic turbine testing includes the selection of a centrifugal pump model GRUNDFOS NK 125-200/176-154 EUP A1F2AE-SBAQE, with a capacity of 1200 GPM and a motor power of 15 HP at 1800 rpm. The dimensions of the pipes are chosen to maintain recommended velocities and avoid issues such as water hammer. A control system is established with a PLC and a variable frequency drive, allowing for adjusting the water flow rate in the test channel. Additionally, the dimensions of the test channel are defined as 0.35 m wide, 0.5 m high, and 5 m long, with an acrylic window for visualizing the turbine behavior. The total project costs amount to 19260 USD.

Material and methods

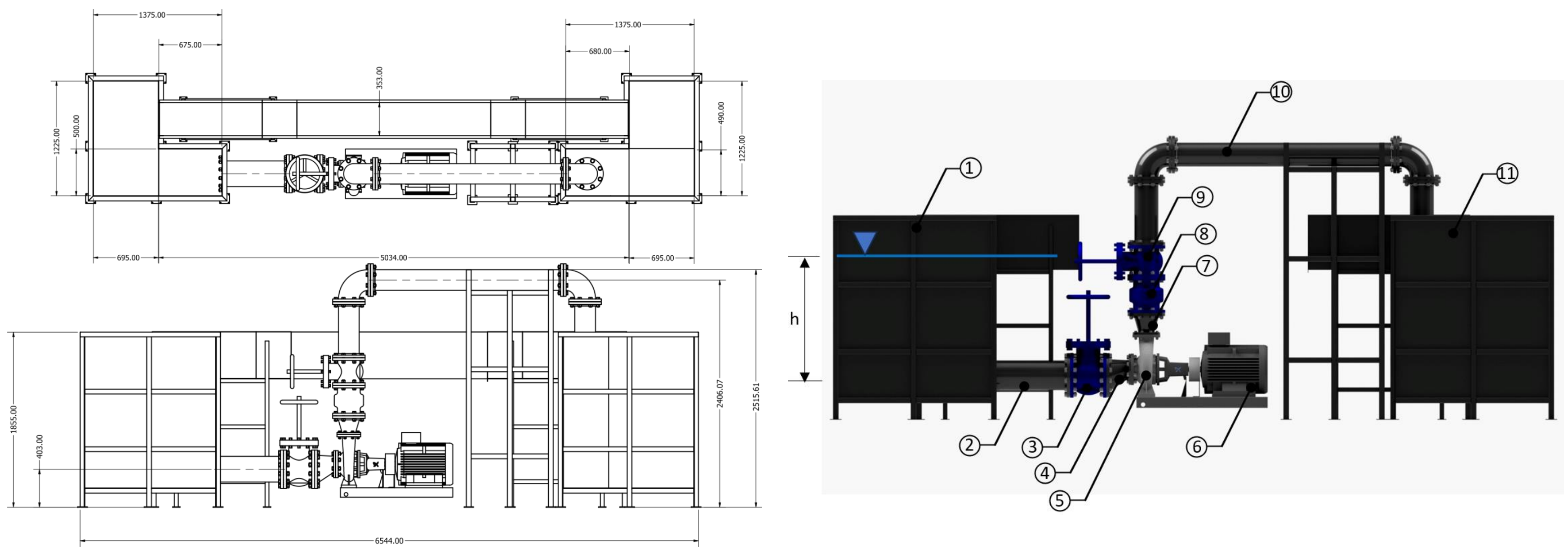
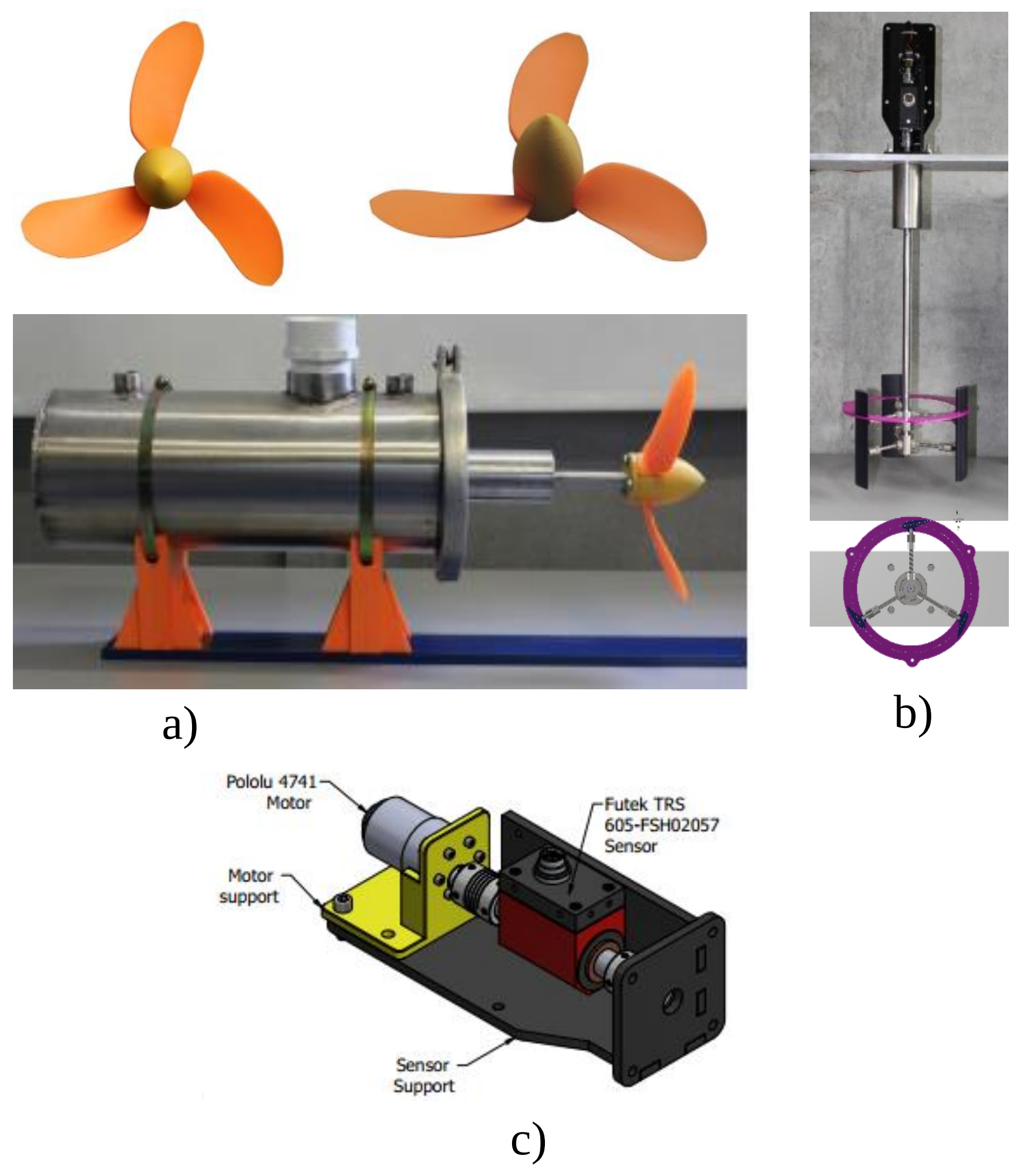


Fig. 1. Detail of the pumping system components. 1) Suction tank, 2) Suction pipe, 3) Gate valve, 4) Eccentric reducer, 5) Pump, 6) Motor, 7) Concentric reducer, 8) Check valve, 9) Gate valve, 10) Discharge pipe, 11) Discharge pipe


a)
b)

c)

Fig. 2. a) Propeller hydrokinetic turbine, b) H-Darrieus hydrokinetic turbine, c) Assemble of measurement and control system

The experimental characterization of the two hydrokinetic turbines was conducted within the specially designed water recirculation channel. The turbines under investigation include a horizontal-axis hydrokinetic turbine (HAHT) and a vertical-axis hydrokinetic turbine (VAHT), depicted in Fig. 2a and 2b, respectively. The HAHT, functioning as a propeller turbine, features a rotor with a diameter (D) of 0.24 m, along with a skew angle of 13.3° and a rake angle of -18.06°. On the other hand, the VAHT is a H-Darrieus turbine with dimensions including a D of 187.5 mm, height (H) of 141 mm, and chord length (C) of 42.5 mm. The H-Darrieus turbine incorporates a NACA 0015 hydrofoil with an angle of attack set at -10°. Both turbines, each equipped with three blades, were fabricated using a 3D-printer system.

The turbine performance evaluation involved the utilization of the coefficient of performance (C_P), C_P is determined by the ratio of the turbine power output to the maximum power available in the free-stream tube of a cross-sectional area (A), and its calculation is articulated in Eq. (1). In the case of the HAHT, A corresponds to the rotor swept area, represented by πR^2. For the VAHT, A is computed by multiplying the rotor H and D..

$$C_p = \frac{T\omega}{\frac{1}{2}\rho A V^3} \qquad (1)$$

where, T represents the torque, ρ denotes the water density, ω is angular velocity, and V is the water free stream velocity. Simultaneously, the tip speed ratio (TSR) is characterized as the proportion between the tangential speed of the blade tip and the upstream flow velocity. The calculation of TSR is governed by Eq. (2), with R representing the turbine radius.

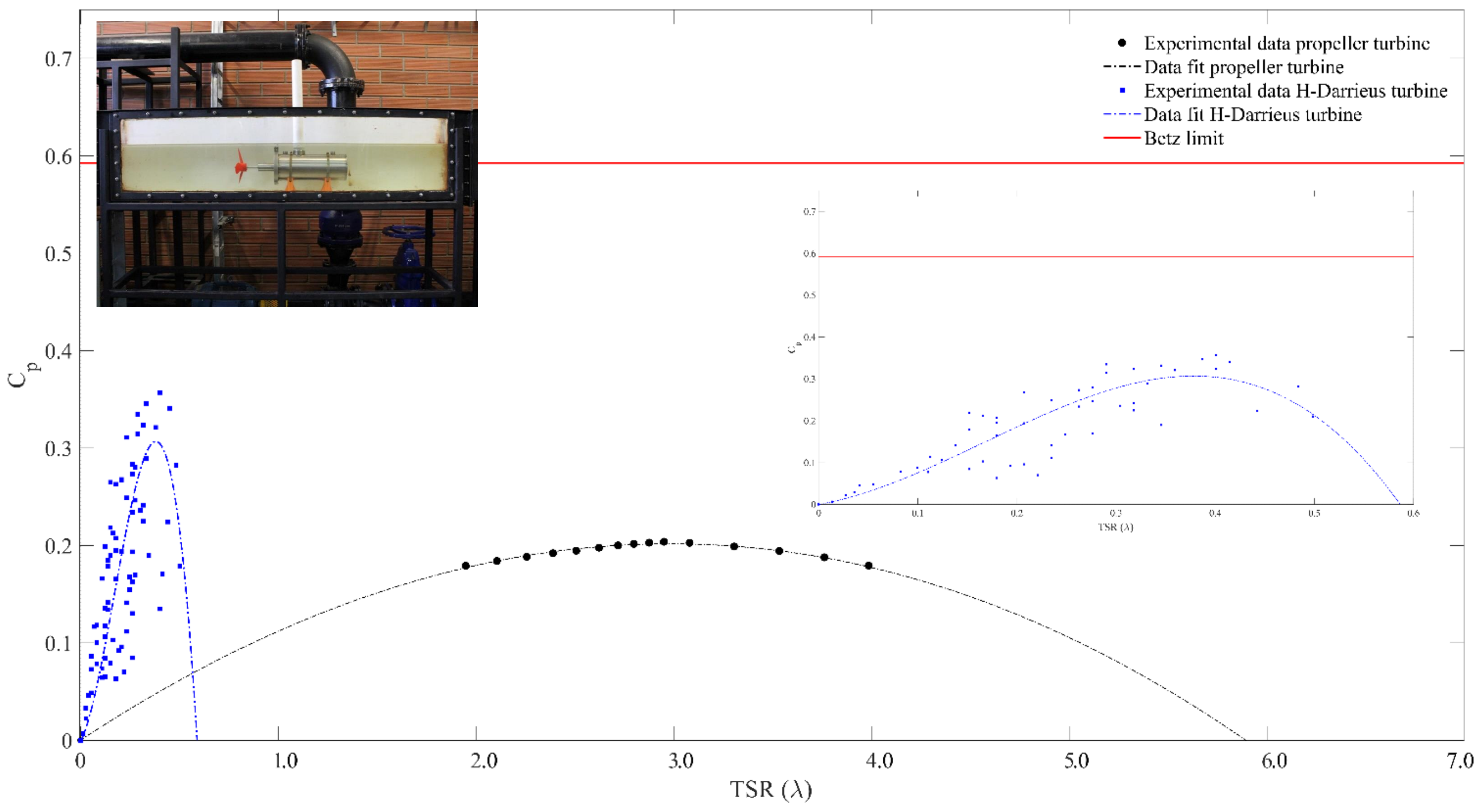
$$TSR = \frac{R\omega}{V} \qquad (2)$$

The experimental setup occurred in a recirculation channel, utilizing a flowmeter (FlowWatch FW450) for water speed measurement and a torque sensor (Futek-Model TR605) with an encoder for torque (T) and angular velocity (ω) measurements. Real-time data recording was enabled by an intelligent digital display (IHH500 pro) connected to the sensor. Torque assessment across various Tip Speed Ratios (TSRs) was conducted using a braking system connected to the torque sensor, employing a direct current motor and reverse current braking approach (Fig. 2c). This system regulated turbine rotation speed by adjusting the braking torque through pulse width modulation (PWM) controlled by a microcontroller. Testing involved aligning the rotors perpendicularly to the flow direction to establish a non-dimensional power performance curve correlating CP with TSR, with results obtained for two rotor configurations

Results and discussion

Fig. 3 compares the turbine performances obtained from the experiment. The results indicated a C_P peak of 0.3076 at a λ of 0.380 for the H-Darrieus turbine. In contrast, a C_P of 0.2129 at a λ equal to 2.952 was recorded for the propeller turbine. To harness electrical energy, generators coupled to the turbine typically operate at specific RPM levels, usually at high RPM. Given that hydrokinetic turbines, especially the current H-Darrieus turbine, generate power at low RPM, incorporating a gearbox between the turbine and the generator becomes necessary. This gearbox serves to elevate the ω from the turbine's low-speed main shaft to a high-speed shaft, effectively linking with an electrical generator.

The C_P was notably higher compared to that of the propeller hydrokinetic turbine. The H-Darrieus design exhibited a simpler structure than the propeller turbine, as the latter's blade featured a more intricate geometry, demanding precision in machining and manufacturing. Consequently, the straightforward design of the H-Darrieus turbine positively impacts the manufacturing process, potentially leading to a reduction in total costs. In the case of a propeller turbine, both the gear and the generator need to be submerged underwater.



The results suggest that both turbines have the potential to make substantial contributions to Colombia's future renewable energy landscape. The H-Darrieus turbine exhibits a CP approximately 44.44% higher than that of the propeller turbine, with the latter presenting a comparatively lower CP. However, the propeller turbine features a higher ω and less fluctuation in T, mitigating structural concerns within the turbine..

Fig. 3. Power coefficient (C_p) *vs.* tip speed ratio (TSR) values

Conversely, in a VAT, the generator can be attached to one end of the shaft, allowing it to be positioned above water and potentially lowering costs associated with water-sealed technology. Despite the advantages of the H-Darrieus turbine, it exhibits suboptimal starting characteristics and a less stable ω when compared to the propeller turbine. Additionally, the H-Darrieus turbine's blades undergo an unstable peak load during operation, potentially causing vibrations and reducing its overall lifespan.

Conclusion

The design and implementation of a water recirculation channel for the testing of hydrokinetic turbines in a controlled environment signify a pivotal step towards advancing sustainable and efficient technologies. The establishment of such an experimental facility is crucial for systematically evaluating the performance and efficiency of hydrokinetic turbines. This controlled setting allows for accurate measurements and assessments, providing valuable insights for the development of innovative and sustainable solutions in the field of renewable energy. Furthermore, the adaptability of the water channel allows for the evaluation of different turbine models, promoting a thorough exploration of their capabilities and enriching the broader understanding of hydrokinetic energy conversion technologies. This facility stands as a foundational element for research and development, providing a launchpad for the advancement of environmentally sustainable and impactful energy solutions.

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References