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SIMCENTER AMESIM-BASED OPTIMIZATION OF AN EXPERIMENTAL TEST STAND FOR ULTRA-LOW HEAD HYDRAULIC TURBINES OPTIMIZATION

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Abstract: *The aim of this paper is to simulate and optimize an experimental test stand designed for optimization of ultra-low head hydraulic turbines. By modeling various hydraulic parameters and configurations, the study seeks to identify the optimal geometry of a calibrated orifice capable of maintaining a stable water level in the upper tank, ensuring efficient operation under variable flow conditions, with a maximum flow rate of 100 L/s.*

Keywords: *Simcenter Amesim optimization, experimental test stand, ultra-low head hydraulic turbines.*

1. Introduction

In recent years, the field of hydroelectric power generation has witnessed a significant shift towards ultra-low head (ULH) hydraulic turbines. These innovative machines have been designed to operate efficiently under very low water heads, typically below 10 meters. The primary objective behind developing ULH turbines is to harness energy from small-scale and run-of-river hydropower resources that were previously considered uneconomical or impractical for traditional hydroelectric power plants.

One of the most significant advantages of ULH turbines lies in their compact design. Unlike larger, more conventional hydroelectric turbines, these machines are designed to be smaller and more agile, making them ideal for installation in confined spaces such as small-scale hydropower installations, water treatment facilities, or even residential homes. This compactness not only simplifies the installation process but also reduces visual impact on the surrounding landscape, a crucial consideration for environmentally conscious developers.

The efficiency of ULH turbines is another notable aspect that sets them apart from their larger counterparts. These machines have been optimized to achieve high efficiency rates (>90%) under low head conditions, making them an attractive option for applications where water heads are limited or variable. This improved efficiency translates directly into increased power output and reduced energy losses, further enhancing the overall viability of ULH turbines in various hydropower contexts [1, 2].

Another significant benefit associated with ultra-low head hydraulic turbines is their scalability. These machines can be designed to accommodate a wide range of capacities (from small-scale residential applications to larger commercial projects), making them an attractive option for developers seeking flexibility and adaptability in their power generation solutions. Additionally, ULH turbines are capable of operating in various flow regimes, including low-flow conditions, which makes them suitable for intermittent or variable water resources.

The environmental benefits associated with ultra-low head hydraulic turbines cannot be overstated. These machines offer a clean and renewable alternative to traditional fossil-fuel-based power generation, reducing greenhouse gas emissions and minimizing visual impact on the surrounding landscape. Furthermore, ULH turbines can help reduce energy losses in existing infrastructure by providing an efficient means of generating electricity from small-scale hydropower resources.

Despite their many advantages, ultra-low head hydraulic turbines also present some challenges that must be carefully considered during design and implementation phases. One significant limitation lies in their reduced efficiency at very low head conditions (typically < 5 m), which can limit their applicability in certain situations. Additionally, ULH turbines may struggle with variable flow rates, requiring additional control systems to maintain optimal performance [3, 4].

Ultra-low head hydraulic turbines have been successfully integrated into a variety of power generation contexts, from small-scale residential installations to larger commercial projects. Some notable examples include:

- Small-Scale Hydropower: ULH turbines are ideal for small-scale hydropower applications (e.g., residential homes, community centers) where water heads are limited or variable.
- Run-of-River Systems: These machines can be used in run-of-river systems where the flow rate is variable and water heads are low.
- Water Treatment Plants: ULH turbines have been integrated into some water treatment plants to provide power for pumping stations or other essential equipment.

Optimizing experimental test stands is crucial for ultra-low head applications as it allows researchers and engineers to accurately assess the performance of low-head hydraulic turbines under various conditions. This optimization process involves designing and testing different turbine configurations, materials, and operating parameters to achieve maximum efficiency and reliability.

The importance of optimizing experimental test stands can be attributed to several factors:

- Improved efficiency: Optimized test stands enable researchers to identify areas for improvement in turbine design, leading to increased efficiency and reduced energy losses.
- Enhanced safety: By simulating real-world conditions, optimized test stands help ensure the safe operation of low-head hydraulic turbines under various scenarios.
- Cost savings: Optimizing experimental test stands can lead to cost savings by reducing the need for expensive field testing and minimizing downtime [5, 6].

As research continues to advance, ultra-low head hydraulic turbines will likely become even more efficient and adaptable. Future developments may focus on improving efficiency at very low head conditions (typically < 5 m), enhancing control systems for variable flow rates, and exploring new applications where these machines can provide significant benefits.

Ultra-low head hydraulic turbines represent a promising development in the field of hydroelectric power generation. Their compact design, high efficiency, scalability, and environmental benefits make them an attractive option for various hydropower applications. However, careful consideration must be given to their limitations, including reduced efficiency at very low head conditions and potential challenges associated with variable flow rates.

In the near future, we expect to see increased adoption of ultra-low head hydraulic turbines in various power generation contexts, including small-scale residential installations, run-of-river systems, water treatment facilities, and commercial projects. As this technology continues to evolve, it will undoubtedly play a more prominent role in shaping our energy landscape for years to come [7, 8].

2. Material and Method

The experimental test stand was designed to replicate operating conditions for ultra-low head (ULH) hydraulic turbines, with a focus on maintaining stable water levels in the upper tank under varying flow conditions. The setup consisted of an upper tank serving as the primary water reservoir, a lower tank that received discharged water, and a centrifugal pump capable of delivering flow rates of up to 100 L/s to recirculate water from the lower tank to the upper tank. A calibrated orifice was included as the key component to control flow rate and ensure water level stability in the upper tank. Various geometries of the orifice were tested to identify an optimal design, ultimately selecting a geometry of Ø125 x 100 mm. Simcenter Amesim software was employed to model the hydraulic behavior of the test stand and simulate its performance (**Figure 1**). The simulation process began with system modeling, where components of the test stand were represented using the software’s thermal-hydraulic library. Flow restrictions and orifice geometries were defined as boundary conditions, and steady state as well as transient flow scenarios were simulated to evaluate system performance under varying conditions.

The objectives of the study are to analyze the behavior of the experimental test stand under unrestricted flow conditions, evaluate the performance of the system with specific flow restrictions applied, and investigate the impact of varying flow rates on the stability and performance of the experimental stand when flow restrictions are in place. Additionally, the study aims to assess critical parameters, including the pressure drop across the calibrated orifice, water flow rate, and maximum dissipated power on calibrated orifice.

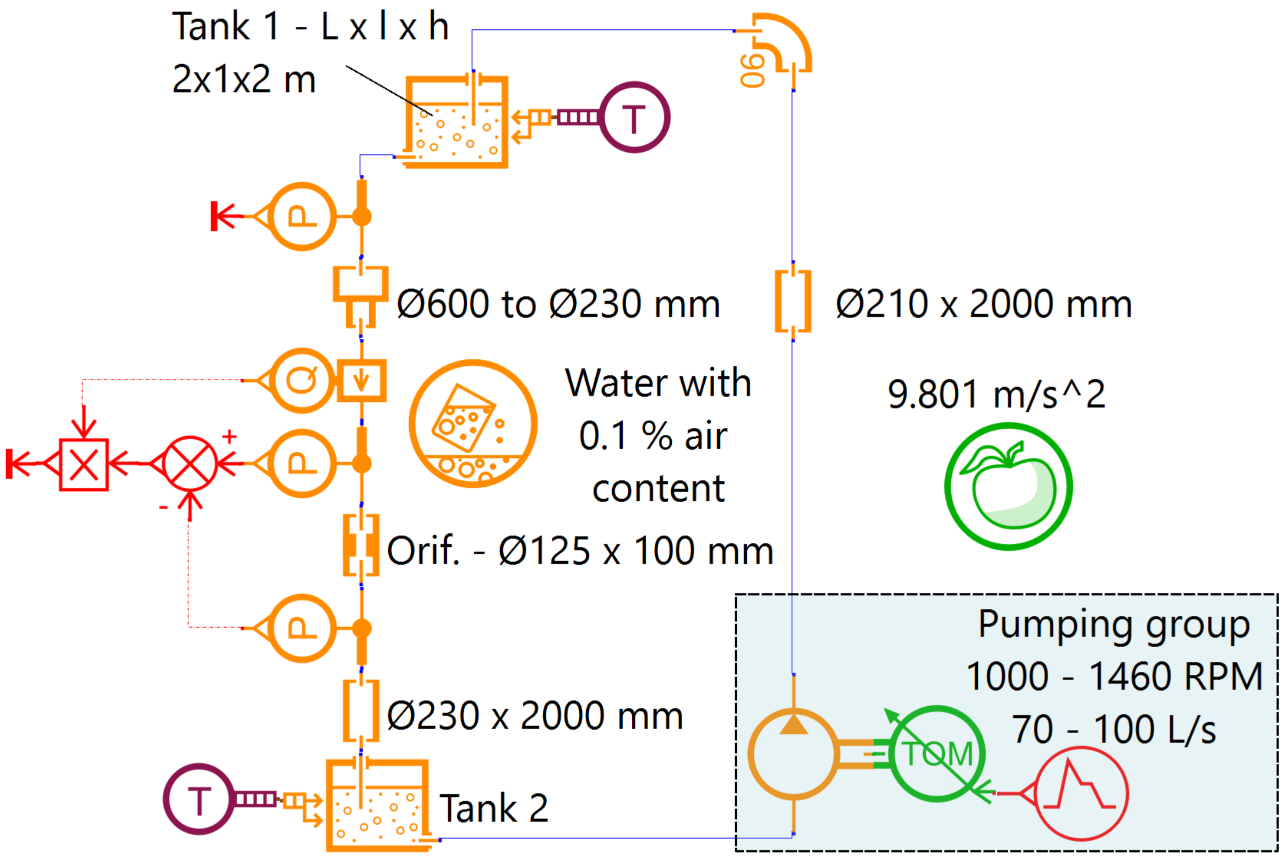

Fig. 1. Simulation network of the test stand for ultra-low head hydraulic turbines optimizations

Optimization of the system involved simulating multiple orifice geometries to identify a configuration that maintained a stable water level in the upper tank while minimizing energy losses. Key performance metrics evaluated in this study included pressure drop across the orifice, flow rate stability, power dissipation, and water level fluctuations in the upper tank.

3. Results

After running the simulation model, several graphs were plotted, related to the tree scenarios studied.

In **Figure 2,** the behavior of the experimental test stand under unrestricted flow conditions is presented. In this figure, it can be seen that the upper tank empties in less than 12 seconds through the 230 mm internal diameter pipe connecting the two basins. The water flow rate decreases because the water column pressure decreases.

Figure 3 presents the behavior of the experimental test stand under restricted flow conditions by calibrated orifice. In this figure it can be seen that the value of the flow rate pumped into the upper tank and the flow rate drained from the upper tank have the same value; also on the same graph it can be seen that both the pressure at the base of the upper tank and the water level in it remain constant.

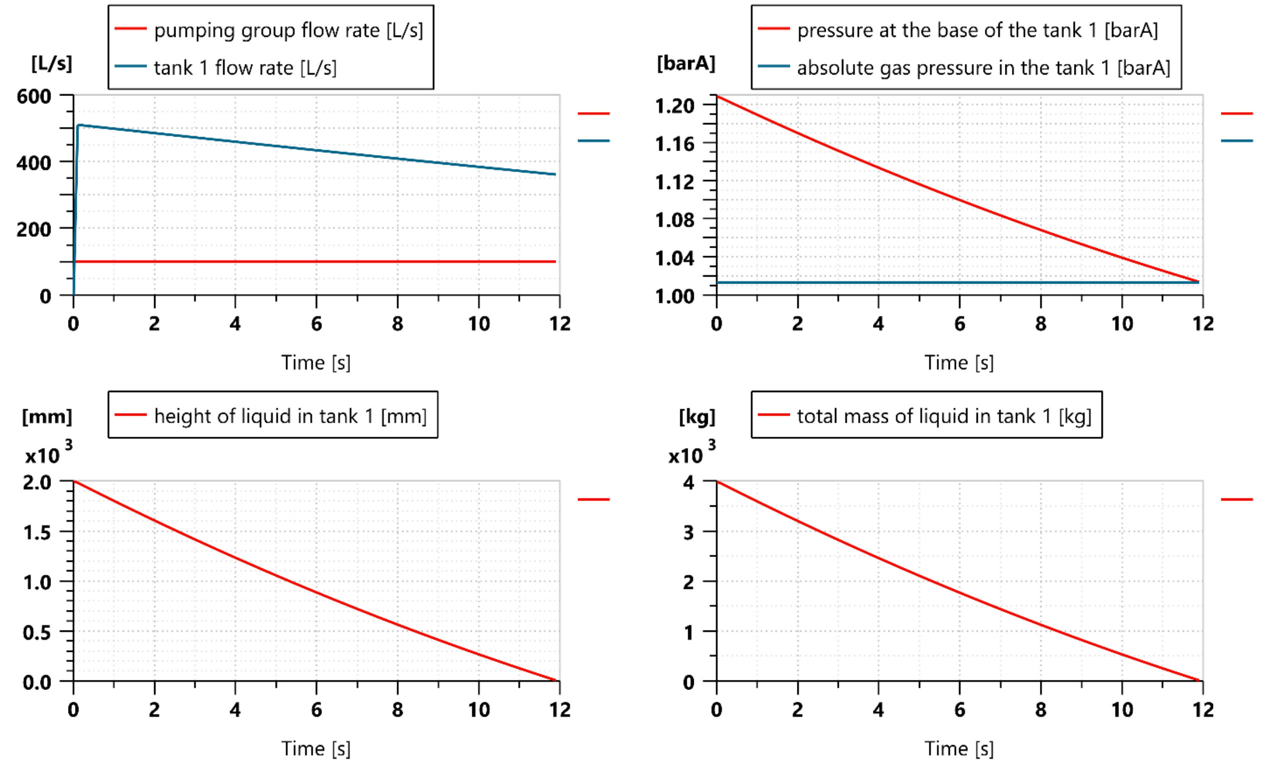

Fig. 2. Behavior of the experimental test stand under unrestricted flow conditions.

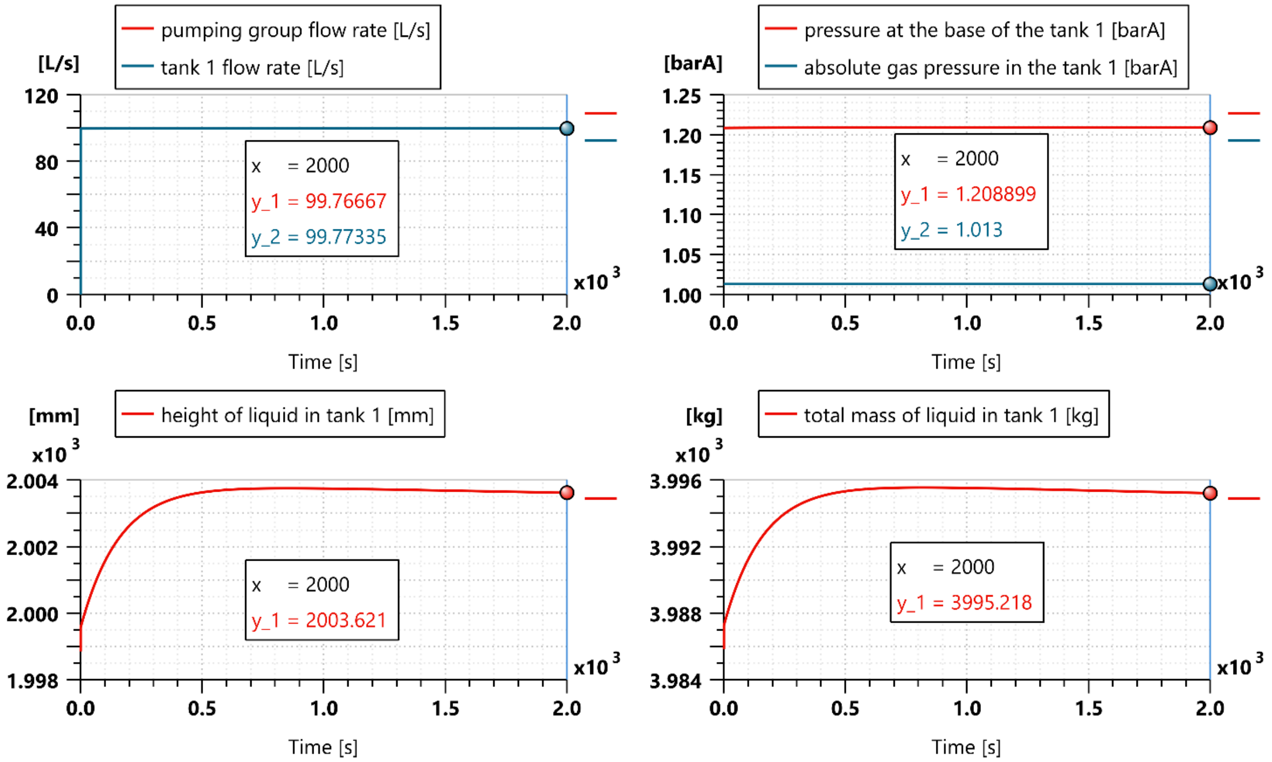

Fig. 3. Behavior of the experimental test stand under restricted flow conditions.

Figure 4 shows the behavior of the experimental test stand under restricted flow conditions and variable flow rate. In this graph, it can be seen that all parameters vary directly proportionally with the pumped flow rate, an exception being atmospheric pressure.

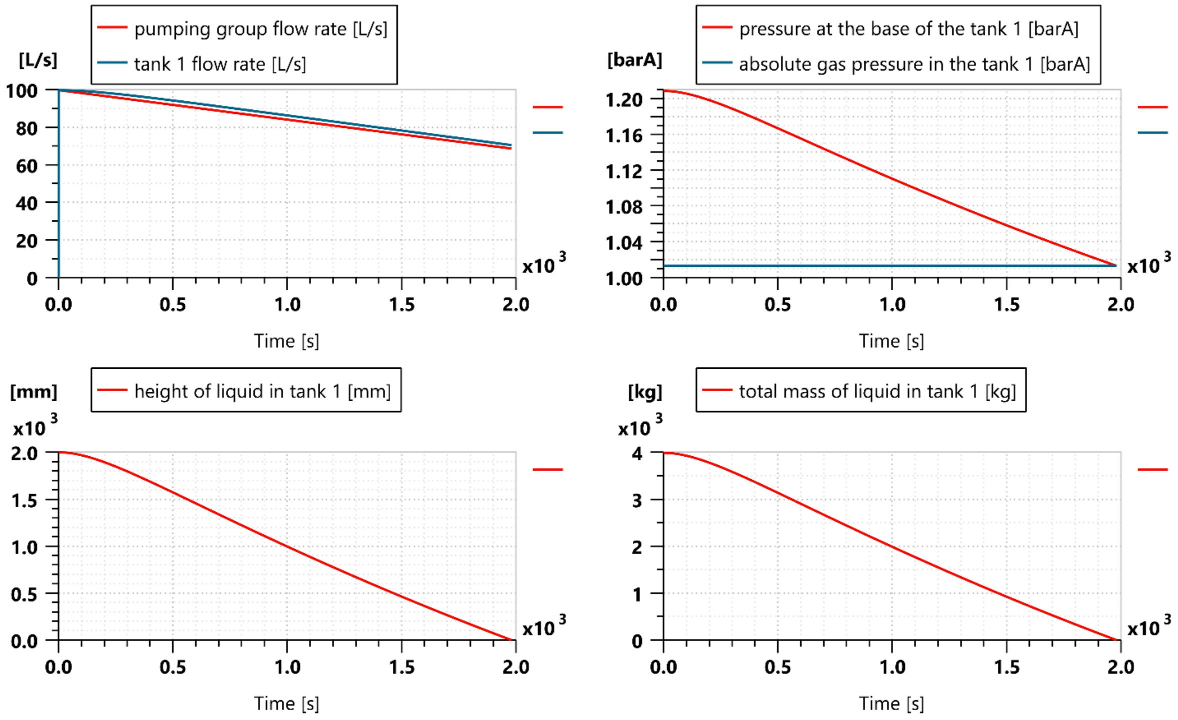

Fig. 4. Behavior of the experimental test stand under restricted flow conditions and variable flow rate.

Figure 5 shows the dependence between heights of the water column (water level) and pressure the as well as the flow rate and pressure.

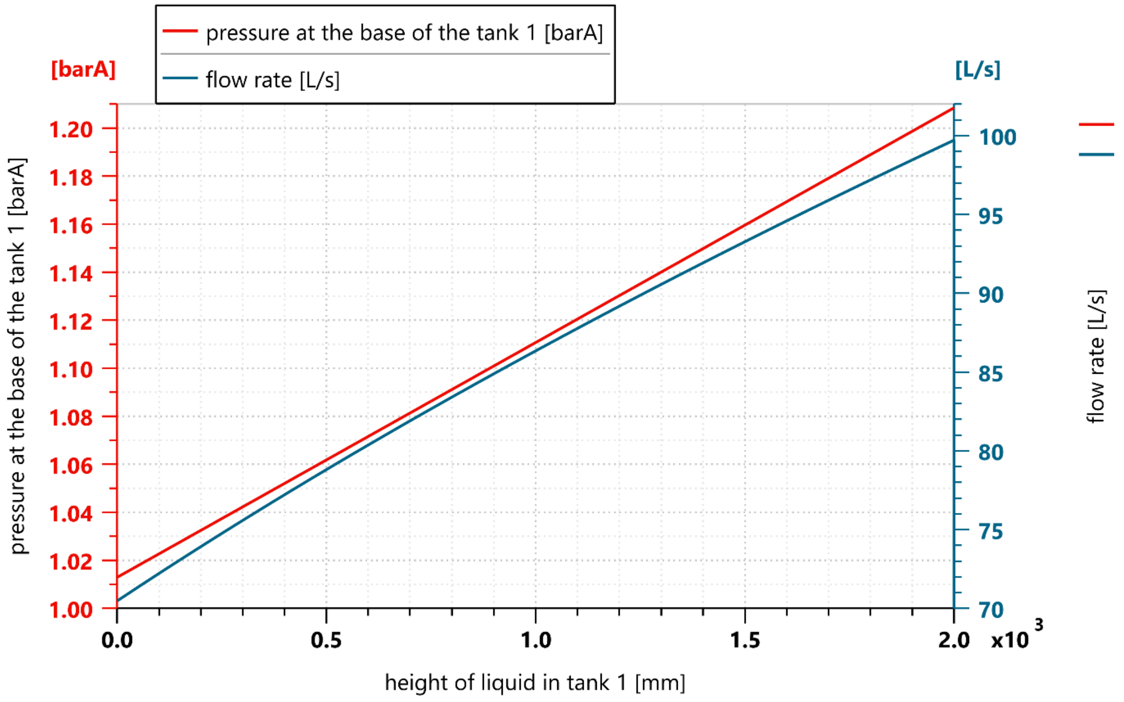

Fig. 5. Tank 1 pressure and flow rate vs. liquid height.

The time variation of the flow rate and the multiple hydraulic parameters of the calibrated orifice are presented in **Figure 6**. Most of the parameters have a variation directly proportional to the time variation of the flow rate except for the zeta coefficient whose variation is inversely proportional to the flow rate. The flow coefficient (cq) does not vary in time.

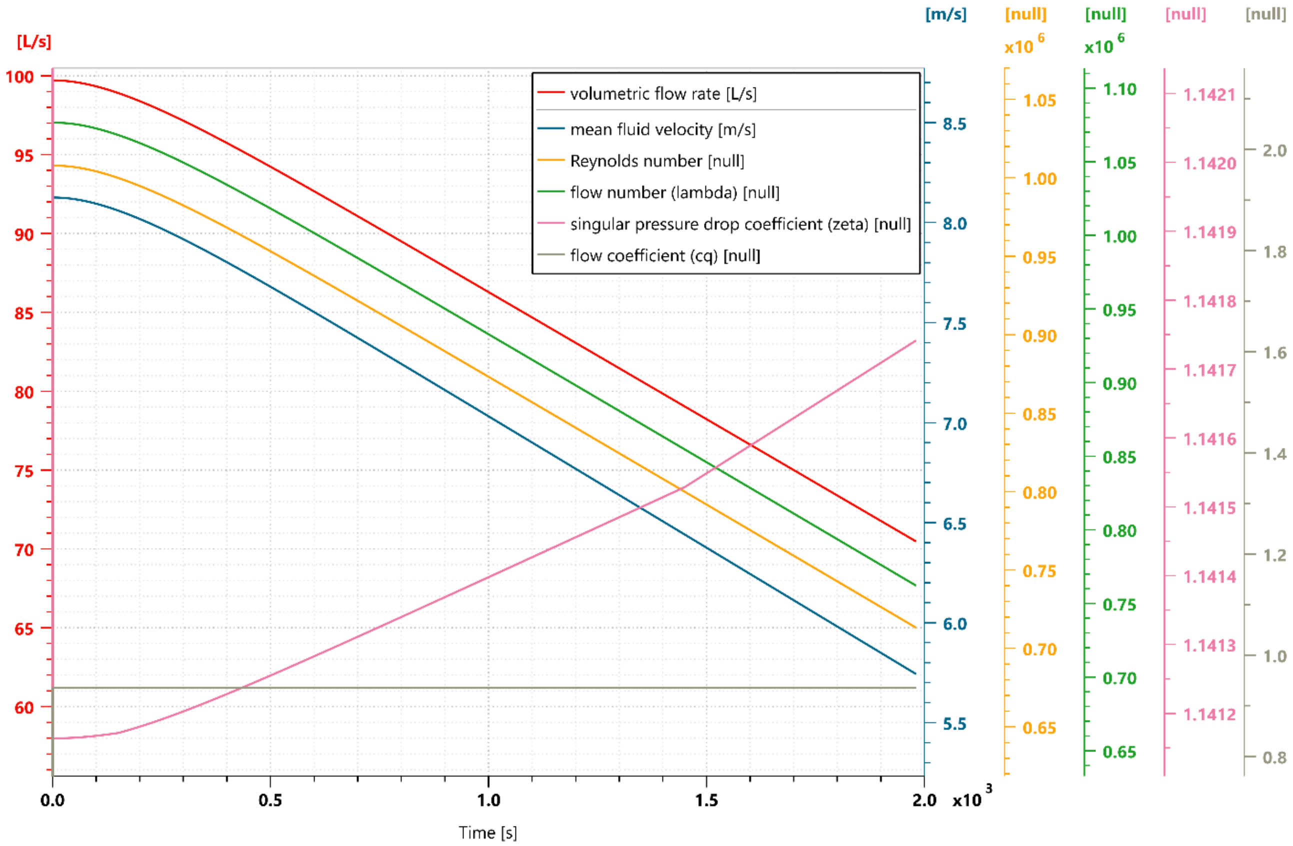

Fig. 6. The dynamics of flow rate and various hydraulic parameters through calibrated orifice.

Figure 7 illustrates the relationship between the pressure drop, the height of liquid in the upper tank, and the hydraulic power dissipated by the resistive source (calibrated orifice). The horizontal axis represents the pressure drop (in bar), while the vertical axis corresponds to the liquid height (in mm). The color gradient, ranging from blue (low values) to red (high values), indicates the power consumption in watts. **Figure 8** focuses on the relationship between the pressure drop, flow rate (Q), and the hydraulic power dissipated by the resistive source. The horizontal axis again represents the pressure drop (in bar), while the vertical axis displays the flow rate (in L/s). The color map indicates the power consumption, with values rising from blue (low power) to red (high power). The graph shows that as both the flow rate and pressure drop increase, the power rises significantly. The red zone, corresponding to the highest power values, occurs at maximum flow rates (100 L/s) and the largest pressure drops, whereas the blue areas indicate minimal power consumption at lower flow rates and pressure drops. The last two figures shows how the power required by the calibrated orifice is influenced by hydraulic parameters. **Figure 7** emphasizes the effect of the liquid height in the upper tank, which determines the potential energy influencing the power. In contrast, **Figure 8** focuses on flow rate, illustrating the dynamic influence of moving water. Despite these differences, both figures consistently show that an increase in pressure drop, whether paired with higher liquid levels or higher flow rates, leads to a substantial rise in power. Together, the graphs provide complementary insights into the hydraulic system's behavior, aiding in the optimization of the orifice geometry for stable and efficient operation in ultra-low head hydraulic turbine test stands.

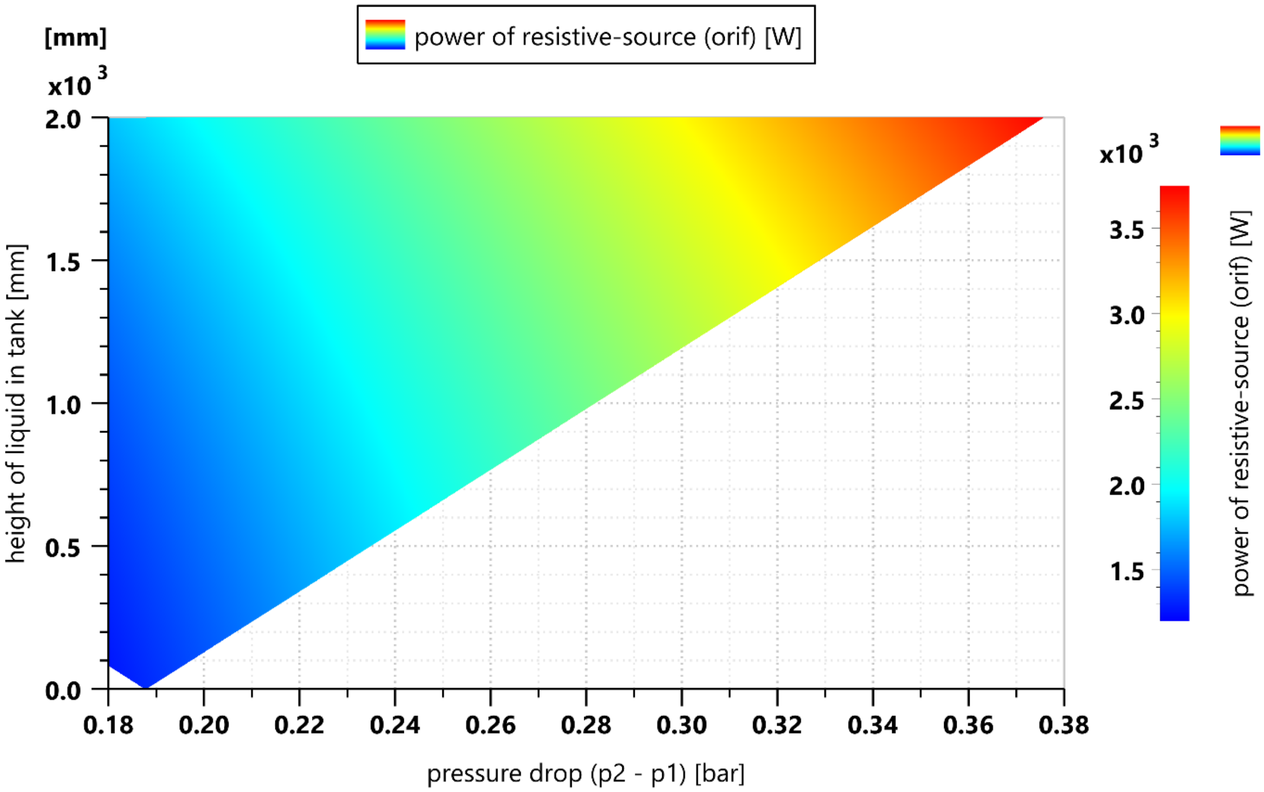

Fig. 7. The hydraulic power dissipated by the hydraulic orifice as a function of the pressure drop and the height of the liquid column.

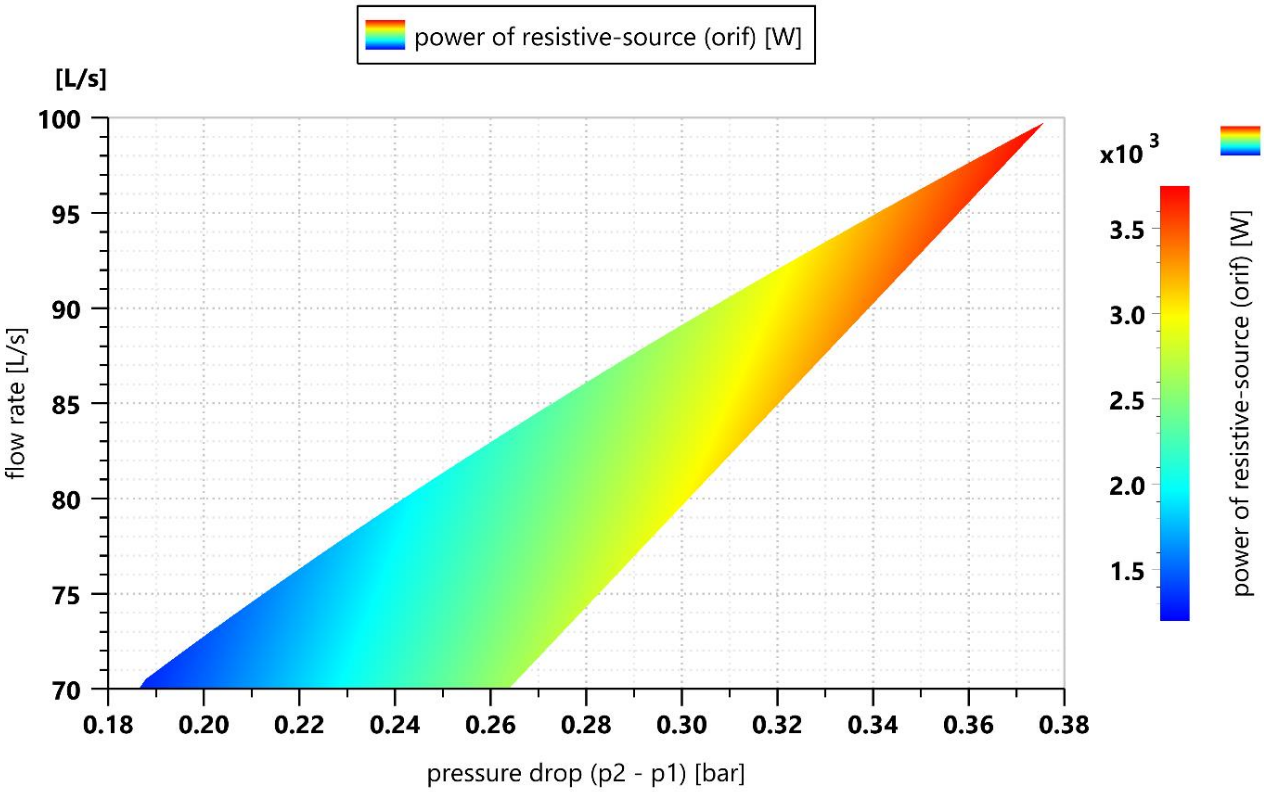

Fig. 8. Hydraulic power dissipated by the hydraulic orifice depending on pressure drop and flow rate.

4. Conclusions

The study found that a calibrated orifice with a geometry of Ø125 x 100 mm provides the most effective means of maintaining a stable water level in the upper basin. Without this calibrated orifice, the upper basin drains in under 12 seconds. However, with the orifice in place, the water level remains nearly constant, demonstrating its suitability for ULH hydraulic turbine optimization. Additionally, the pressure drop across the orifice varies between 0.18 and 0.38 bar for flow rates from 70 to 100 L/s, while the power dissipated through the orifice ranges from 1.2 to 3.7 kW. These findings underscore the orifice's role in managing flow and energy dissipation effectively within the experimental stand.

Acknowledgments

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