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EXPERIMENTAL STUDY OF THE PERFORMANCE OF A PELTON TURBINE OF A MICRO POWER PLANT FOR DIFFERENT OPERATING CONDITIONS

Raul Delgado Currin
Department of Mechanical Engineering, University of La Frontera
Temuco, Chile
Department of Mechanical Engineering - University of Chile
Santiago, Chile.
https://orcid.org/0000-0001-5758-8317

Williams Calderon Munoz
Department of Mechanical Engineering - University of Chile
Santiago, Chile.
https://orcid.org/0000-0003-3786-7495

Juan Carlos Elicer Cortes
Department of Mechanical Engineering - University of Chile
Santiago, Chile.
https://orcid.org/0009-0006-3184-2827

Abstract: In this work, the commissioning of a 10 kW power micro-hydraulic plant has been carried out, with the purpose of carrying out an experimental work to analyze the effect of the variation of the operating conditions on the performance of a turbine. pelton. Although the characterization of the Pelton turbine has been carried out using different injector diameters, flow rates, with different braking powers of the shaft, it has not been characterized for different pressure heights, but only the variations of these due to the effect of the flow rate variation and injector diameters, considering power generated in the turbine shaft of 70 (W) (Rafae Alomar et al., 2022a)In this work, an experimental characterization of a turbine is carried out considering different injector openings d, pressure heights H and flow Q. In addition, different electrical consumptions are applied P_{elect} connected to the generator to obtain the performance of the Pelton turbine. The experimental results show that the increase in the injector opening leads to a reduction in the input power due to the decrease in the pressure head (H) (Anagnostopoulos et al., 2012). There is an optimal performance of the turbine influenced by the electrical consumption applied to the electrical generator, given the increase in torque and pressure to supply the necessary power. It is also observed that when considering the speed of the constant turbine-generator shaft for each test, it is obtained that the torque and power in the shaft are increasing, both by increasing the electrical consumption applied to the electrical generator and by increasing the shaft rotation speed. On the other hand, an increase in performance is observed when the rotation speed increases and the electrical consumption applied to the electrical generator decreases. The best hydraulic performance of the turbine was 71% and it is achieved for conditions with a shaft rotation speed of 630 rpm, applying an electrical consumption of 3 kW to the electrical generator.

INTRODUCTION

The Pelton turbine was created in 1879 by Lester Pelton, and used for hydroelectric power generation since 1888 and patented in 1889 (Breeze, 2018). This hydraulic turbine transforms potential energy into mechanical energy from a hydraulic jump, which later transforms this energy into electrical energy using an electrical generator.

To obtain the highest possible efficiency in the generation of electrical energy from hydroelectric plants, it is important to know the behavior of the variables that we can monitor, such as flow, touch, turbine rotation speed, vibrations, etc. in order to quantify the best point of operation of the system(Rafae Alomar et al., 2022a)

Although characterizations of the Pelton turbine have been carried out using different injector diameters, flow rates, and pressure height, they have only been carried out applying different braking powers of the shaft and do not consider the analysis using an electrical generator or electrical consumption applied to the generator (Anagnostopoulos et al., 2012; Elgammi & Hamad, 2022; Rafae Alomar et al., 2022b). Rather, they focus on the application of the brake system to simulate the load on the turbine shaft and, based on this, measure torque and speed of rotation of the shaft. Mention, in addition, that they consider a low power generated in the turbine shaft, such as 70 (W) (Rafae Alomar et al., 2022b) and 10 0 (W)(Elgammi & Hamad, 2022)

Therefore, in this work, an experimental analysis and characterization of a 10 kW Pelton turbine is carried out, considering different injector openings (d), pressure heights *(H)* and flow *(Q) in the tests. In addition, different* electrical (P_{elect}loads) applied to the electrical generator are used, simulating the electrical consumption to which the electrical generator is subjected, in order to analyze the behavior of the turbine's efficiency under scenarios such as:

- Variation of the injector opening considering a constant electrical consumption on the generator.
- Electric consumption variation considering a constant injector opening
- Variation of electrical consumption applied to the generator considering the constant speed of rotation of the turbine-generator shaft.

The hydraulic performance of the turbine varies between 50 and 71% for an opening of 25% and 100% respectively, considering that the best performance is found for the rotation speeds of the generator turbine shaft greater than 400 rpm.

The increase in speed, torque and power in the turbine-generator shaft is a consequence of the increase in electrical consumption applied to the electrical generator.

MATERIALS AND METHODS

In this study, the experiments to investigate the performance of the Pelton turbine have been carried out in a test bench as shown in Figure 1, this is done for different injector openings (d), pressure height (H), flow discharge (Q) and different electrical loads connected to an electrical generator. An Optiflux2000/IFC300 model mechanical/electronic flowmeter has been used to measure the flow rate and a Yokogawa model EJX11A Pitot tube to measure the inlet pressure to the injector. The flow varies between 25 to 115 $\frac{m^3}{h}$. The fluid is driven by a KSB Etabloc 80-250 pump, which circulates the water in a closed circuit, the height and maximum flow delivered by the pump is 40 mca and 129.6 respectively $\frac{m^3}{h}$. The flow and head of the pump are regulated by means of a frequency inverter Model HC 800. The circuit pipes have a diameter of 4 (in.)

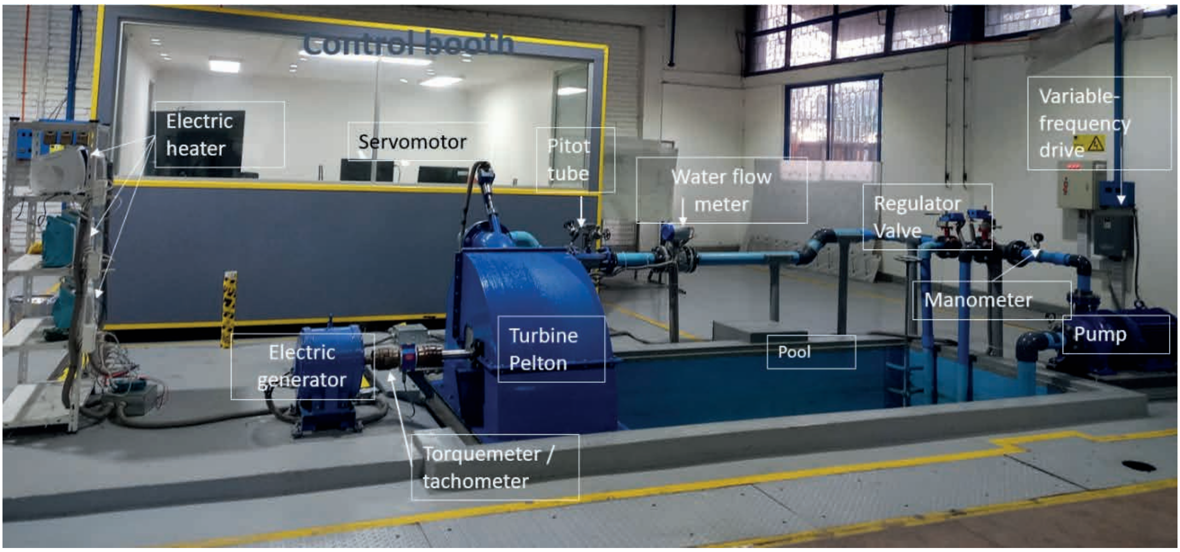

Figure. 1. Micro hydroelectric power plant test bench

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The dimensions of the turbine runner blades are shown in Figure 2 (right), where the runner is made of mechanized duraluminium, with an electrostatic paint and varnish finish, it consists of 17 blades installed on its periphery as shown in Figure 2 (left). The diameter of the wheel is 240 mm, the diameter of the shaft that joins the turbine with the electric generator is 50 mm. To measure the torque (in Nm) and the speed of rotation of the wheel in rpm, a torquemeter-tachometer brand TorqSense, model RWT420, is used.

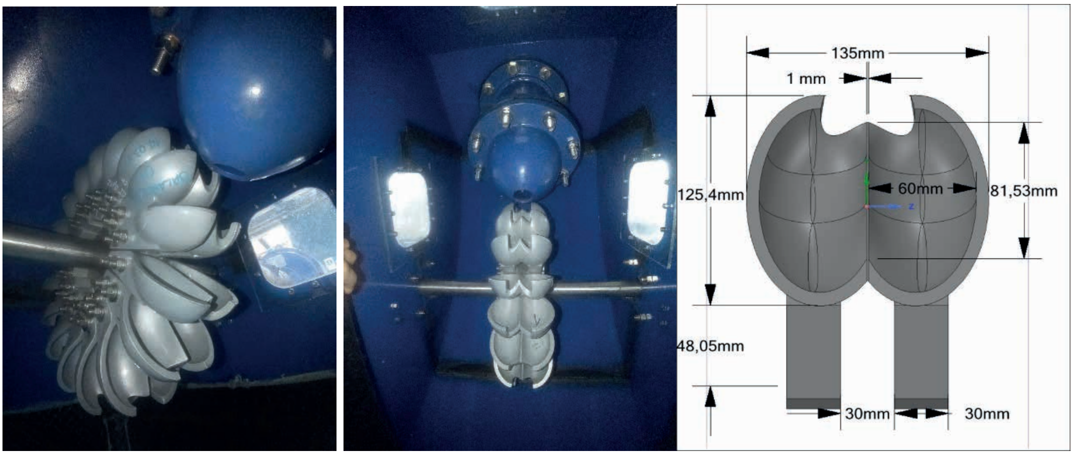


Figure 2. Impeller (left and center) and blade of the Pelton turbine (right).

The turbine shaft is coupled to a synchronous permanent magnet electric generator, with a nominal rotation of 750 rpm, three-phase AC380V and 10 kW of power.

For the tests, the electrical consumptions that are connected to the electric generator have a minimum power load for the three phases of 1.5 kW (0.5 kW for each phase), and a maximum load of 9 kW (3.0 kW for each phase). The electrical loads are applied by electric fan heaters of 2 and 1 kW each, with an intermediate power of 1 and 0.5 kW respectively.

THEORETICAL FOUNDATION OF PERFORMANCE

Next, we will present the equations used to calculate the power and performance of the turbine and the electric generator of the micro hydroelectric power station (Batbeleg & Lee, 2018; Cobb & Sharp, 2013; Gupta et al., 2014; Rafae Alomar et al., 2022b; Stamatelos et al., 2011):

The hydraulic power P_h for an incompressible flow is defined:

$$P_h = \rho g Q H \qquad \text{equation 1}$$

The power generated in the turbine shaft is estimated with:

$$P_b = T\omega \qquad \text{equation 2}$$

Where

$$\omega = \frac{2\pi . N}{60}$$

The hydraulic performance of the turbine is estimated as:

$$\eta_e = \frac{P_b}{P_h} \qquad \text{equation 3}$$

EXPERIMENTAL PROTOCOL

In order to obtain the performance of the turbine and the generator and the system, tests are carried out considering varying the frequency of the pump that drives the fluid to the turbine injector, the variation of the frequency allows to vary the pressure and flow rate, the flow rate variation is performed every 5 $\frac{m^3}{h}$ in a range from 25 to 115 $\frac{m^3}{h}$. Three types of trials are considered:

- *Variation of the opening of the injector of 25, 50, 75 and 100% considering a constant electrical consumption on the generator.* It starts with an injector opening of 25%, with a flow rate of 25 $\frac{m^3}{h}$ and then increases the flow rate every 5 $\frac{m^3}{h}$ to the maximum flow rate allowed in each test. Once this test is finished, the system is turned off, the injector is opened up to 50% and the same procedure is repeated, the same is done for the 75 and 100% opening.

- *Variation of electrical loads (3, 6 and 9 kW of electrical consumption), considering a 100% injector opening.* It begins with a load applied to the generator of 3 kW (1 kW for each phase), with a flow rate of 25 $\frac{m^3}{h}$ and then gradually increases the flow rate every 5 $\frac{m^3}{h}$ up to the maximum flow rate allowed in each test. Once this test is finished, the system is turned off, the power is increased to 6 kW (2 kW for each phase) and the same procedure is repeated. The same is done for the 9 kW electrical load (3 kW for each phase).

- Variation of the electrical load exerted on the generator, (1.5; 3; 4.5; 6, 7.5 and 9 kW of electrical consumption) considering the constant speed of rotation of the turbine-generator shaft. It begins with a 25% injector opening and a load applied to the generator of 1.5 kW (0.5 kW for each phase), with a shaft rotation speed of 200 rpm. Then the load is increased to 3 kW (1 kW per phase) and in turn the flow rate is increased to reach a shaft rotation speed of 200 rpm. This is still true for electrical charges of 4.5; 6, 7.5 and 9 kW of electrical power. Once this test is finished, the system is turned off and then turned on again considering the same procedure, but with a shaft speed of 400 rpm.

Once the tests with the 25% opening are finished, the procedure is repeated with shaft speeds of 200 and 400 rpm for the injector openings of 50, 75 and 100%.

It is worth mentioning that when we talk about "Maximum flow allowed in each test" this is related to the current and nominal working voltage of the heaters (electrical charges) 10 A and 220 V respectively, without prejudice to this we have brought the voltage to 340 V and current of 12 A, without visualizing damage to the heaters.

RESULTS AND DISCUSSIONS

INFLUENCE OF INJECTOR OPENING

Figure 3 shows the variation of the available head (inlet pressure) and the input power as a function of the flow rate variation for injector openings of 25, 50, 75 and 100%. As the opening of the injector increases, the height decreases (or, for that matter, it increases as the injector closes), because the pressure drop decreases due to the increase in the area that gives way to the flow (Gupta et al., 2014). The input power has a behavior similar to the height, this is due to equation 1(Rafae Alomar et al., 2022b).

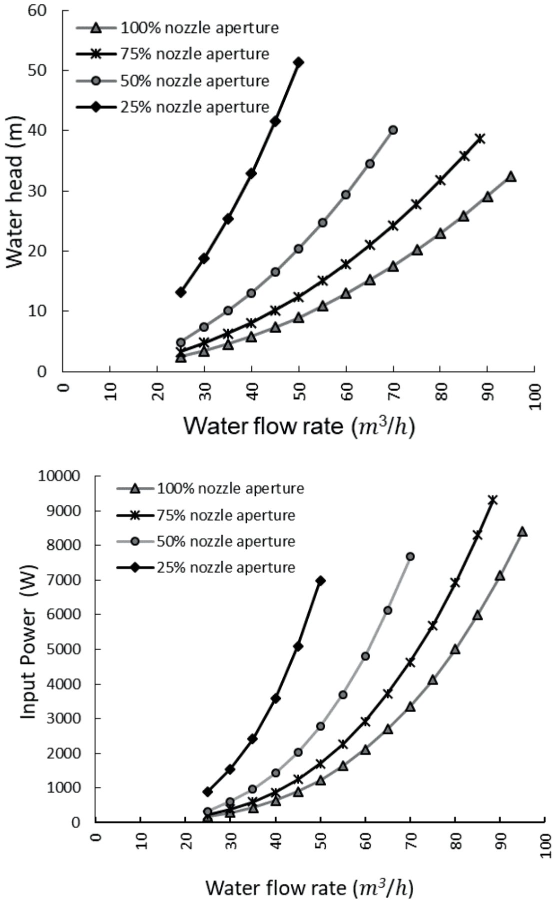


Figure 3. Pressure height (left) and inlet hydraulic power (right), with respect to flow for different injector openings.

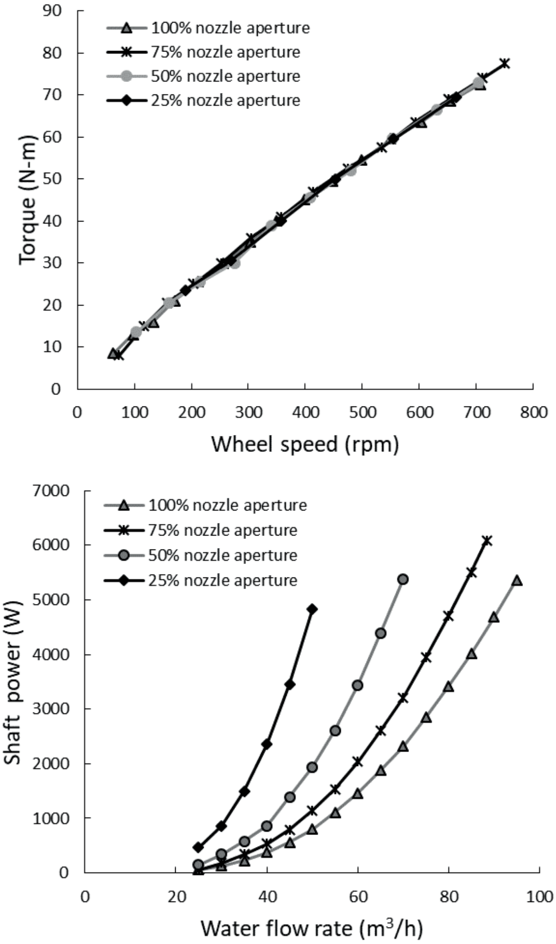


Figure 4. (left) Torque versus shaft speed and (Right) shaft power versus flow for different injector openings.

The Figure 4 (right) and (left) show that the torque and the power of the shaft with respect to the speed of the turbine-generator shaft, have similar behavior, given Equation 2, they are practically linear with respect to the speed of rotation. from the turbine axis, which is expected according to the characteristic curve of the electric generator. In addition, Figure 4 (left) shows that increasing the injector opening also increases the flow rate supplied to the turbine, which is evident, since increasing the area of the choro decreases its speed, having as an effect a decrease in torque and an increase in the speed of rotation of the turbine-generator shaft and an increase in power on the shaft.

On the other hand, the performance of the turbine increases with the increase in the speed of rotation of the shaft, and then begins to decrease from approximately 500, 550, 620 rpm for an injector opening of 100, 75 and 50% respectively., as can be seen in Figure 5. Although the performance has a similar behavior for the openings of 100, 75 and 50%, notably the performance decreases with the opening of 25%, which is produced by the smaller diameter of the jet and greater head loss that it produces. Considering an electrical consumption of 3 kW, the best hydraulic performance is found in the shaft rotation speed range between 400 and 630 rpm with 69 and 71% respectively.

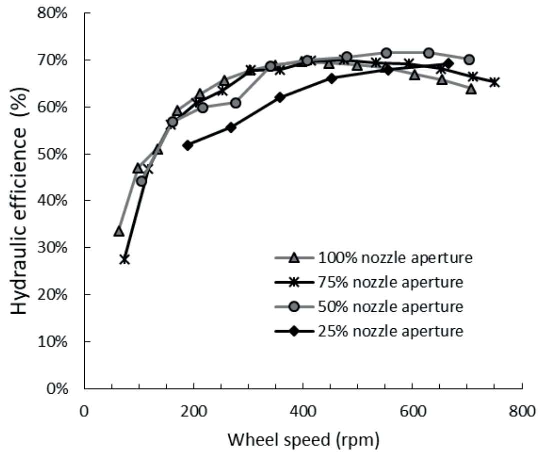


Fig ure 5. Pelton turbine hydraulic performance

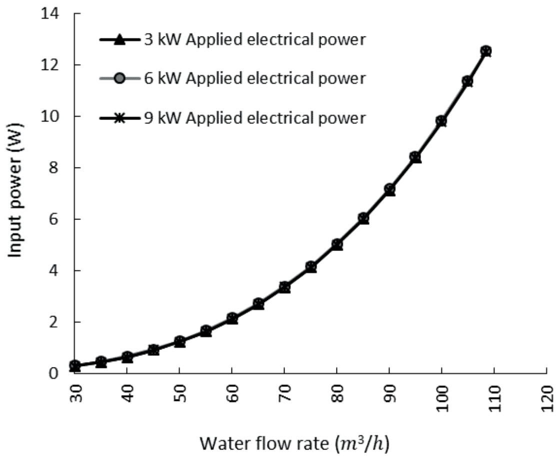
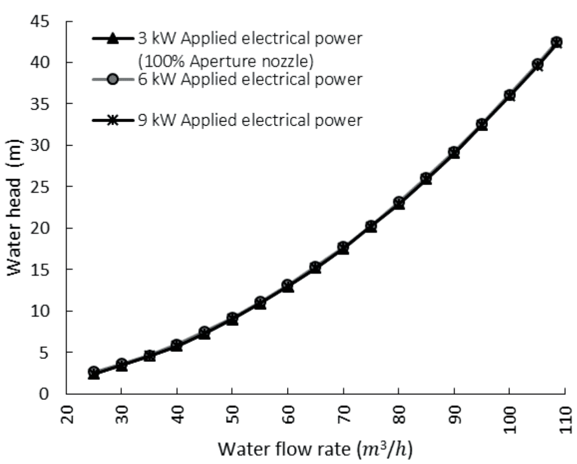


Figure 6. Pressure height (left) and inlet hydraulic power (right), with respect to flow for different electrical loads and injector opening at 100%.

INFLUENCE OF ELECTRICITY CONSUMPTION

Figure 6 shows the variation of the available head (inlet pressure) and the hydraulic input power as a function of the flow rate variation for different electrical consumption, with a 100% injector opening, it is observed that the behavior of the input power is similar to the pressure height, this as a consequence of Equation 1, and that by increasing the flow (Q) we also have an increase in both the inlet pressure and the shaft power.



The torque and power of the shaft have similar behavior with respect to the flow (see Figure 7 (left) and (right)), given Equation 2, this increases as we apply greater electrical loads to the generator, which is explained given that the The generator, with a higher electrical load or electrical consumption applied, tends to deliver a greater amount of current (limited according to its capacities), which is why the torque and power on the generator shaft increase. The flow also increases with the increase in electrical consumption, since it must supply a greater flow to increase the speed of rotation of the turbine-generator shaft, therefore the slopes of the graphs of torque and speed of rotation of the shaft increase with increasing the electrical consumption applied to the electrical generator.

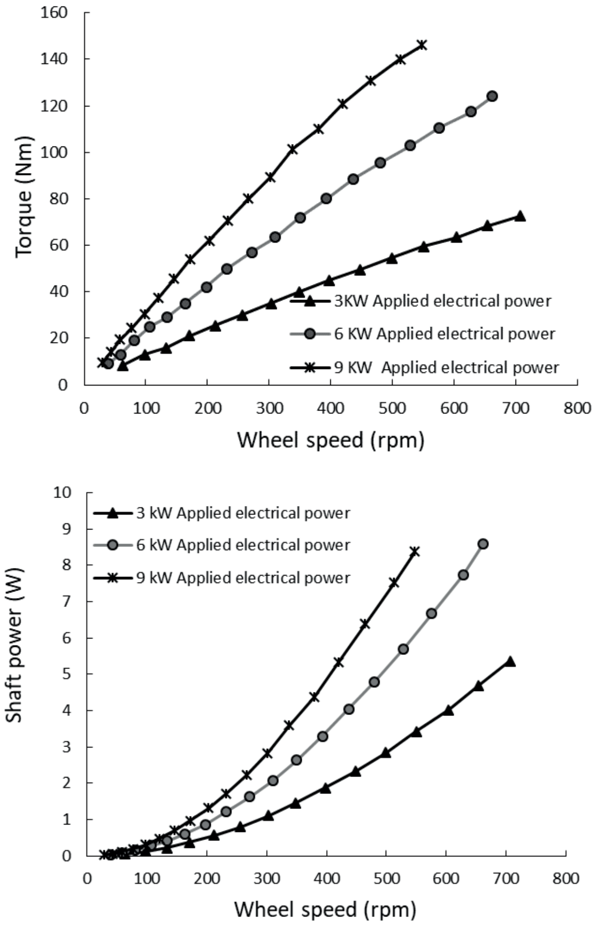


Figure 7. (Left) Torque on the axis and (Right) power on the axis with respect to the speed of the axis for different electrical loads and opening of the injector at 100%.

Figure 8 shows the graph of the turbine performance, which increases when applying lower electrical consumption, this is related to Equation 3, since the inlet pressure increases as more torque is required. When we apply 100% injector opening, the highest hydraulic performance found is 69.6 and 68.5% for a speed of 400 and 550 rpm respectively, applying an electrical consumption of 3 kW of power applied to the generator.

Above a spindle speed of 550 rpm we can see that there is an improvement in performance using an electrical consumption of 6 and 9 kW, observing in turn a drop in performance for the consumption of 3 kW of power. We have observed under this scenario that a good working area for an injector opening of 100% is for a shaft rotation speed range between 400 and 600 rpm.

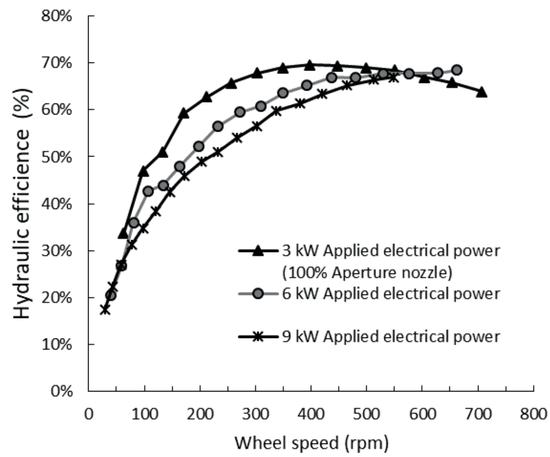


Figure 8. Hydraulic performance of the Pelton turbine for different electrical loads and injector opening at 100%.

INFLUENCE OF CONSTANT SHAFT SPEED AND VARIABLE ELECTRICAL LOADS

Figure 9 (left) and (right) show the variation of the available head (inlet pressure height) and the input power, respectively, as a function of the flow rate variation for different electrical loads (from 1, 5 kW to 9 kW from left to right), in which it is shown that the increase in the speed of rotation of the turbine shaft from 200 to 400 rpm, implies an increase in the flow rate and, in turn, an increase in the head of pressure supplied to the turbine, there being the same trend between both graphs for all cases. It is further evident that as the load applied to the generator increases, the flow rate increases to maintain shaft speed.

In addition, when increasing the opening of the injector from 25 to 100%, the flow (Q) must be increased by 58.3% and the height decreased to 54.23% to achieve the same power of 9 kW at 400 rpm and increase a flow (Q)

55.16% and decrease the height even 55.16% for an applied load of 9 kW at 200 rpm.

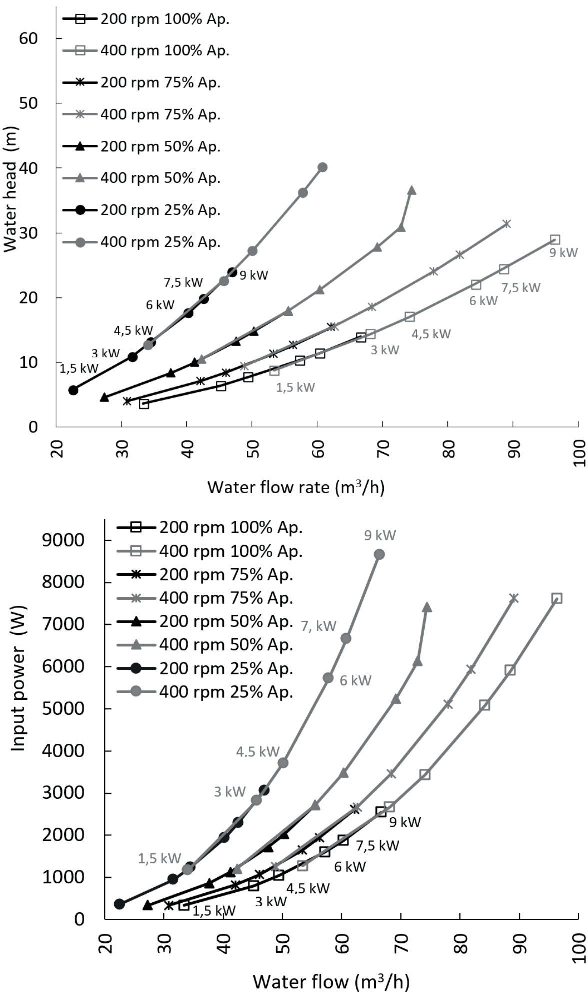


Figure 9. Head of pressure (left) and inlet hydraulic power (right), with respect to flow for shaft speeds of 200 and 400 rpm and injector openings from 25 to 100%.

In Figure 10 (left) we can highlight that, by increasing the power of the loads applied to the generator, it requires more torque and therefore more power in the turbine-generator shaft.

The increase in the opening of the injector requires an increase in the flow to generate the same torque at the output of the turbine-generator shaft. The increase in the speed of rotation of the turbine shaft from 200 to 400 rpm, accompanied by the increase in flow, results in a higher torque for the same electrical consumption supplied to the generator. It must be taken into account that both for the test with 200 and 400 rpm, the electrical consumption applied were the same (as described in the methodology).

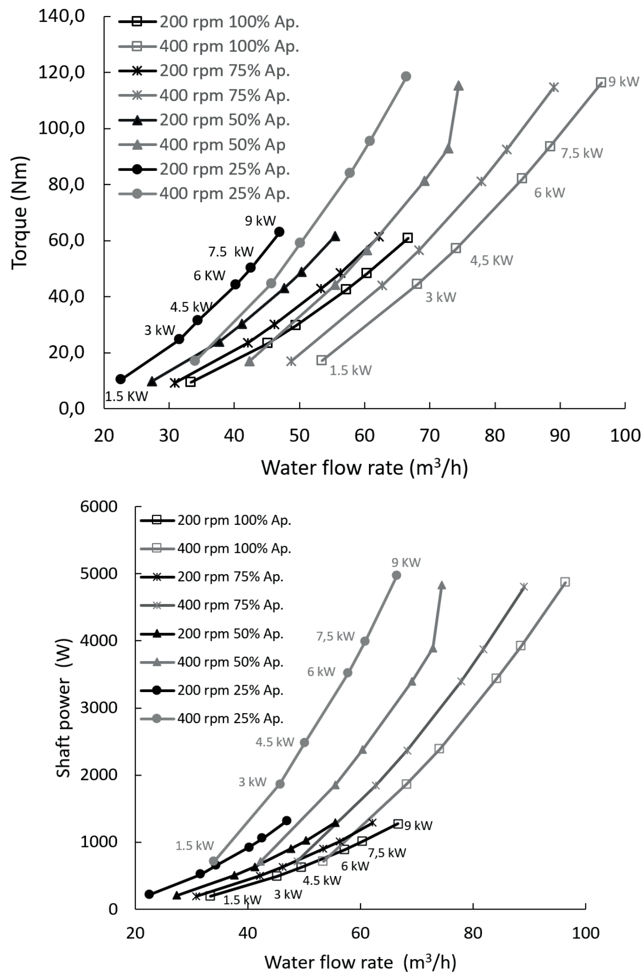


Figure 10 (Left) Shaft torque and (Right) Shaft power with respect to flow for shaft speed of 200 and 400 rpm and injector openings from 25 to 100%.

Figure 11 shows the variation in efficiency as a function of the turbine-generator shaft speed for different electrical loads applied to the generator, considering constant shaft speeds of 200 and 400 rpm. It can be observed that the highest performance is found when using electrical loads of 3 kW, greater opening and greater speed of rotation of the shaft. In addition, performance decreases drastically as electrical consumption increases over 3 kW of power for each case. The best hydraulic performance is obtained with a 100% injector opening, obtaining 66.2 and 69.6% for a speed of 200 and 400 rpm respectively.

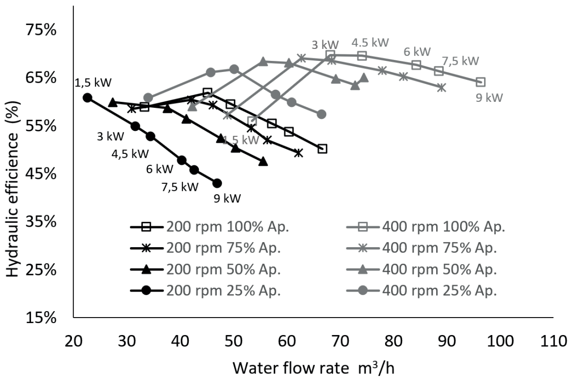


Figure 11. Pelton turbine performance with respect to flow for shaft speeds of 200 and 400 rpm and injector openings from 25 to 100 %.

CONCLUSIONS

For a constant consumption of electrical energy, the decrease in the injector opening generates an increase in torque using the same flow rate.

By using an electrical load of 3 kW, the plateau of the hydraulic performance graph is achieved between 400 and 630 rpm for the cases when an injector opening of 50, 75 and 100% is used, obtaining a maximum performance of 71%. However, when the injector opening is 25%, this is achieved after 600 rpm, this being the most unfavorable condition for this turbine.

By leaving a 100% injector opening, the highest hydraulic performance found is 69.6 and 68.5% for a speed of 400 and 550 rpm respectively.

Regarding the variation of electrical consumption, operating with constant turbine shaft rotation speeds, the best hydraulic performance is obtained with a 100% injector opening, obtaining 66.2 and 69.6% for speed of 200 and 400 rpm respectively.

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