BLADELESS IMPELLER DESIGN TO PUMP ABRASIVE FLUIDS

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Abstract*. The mining process, as well as others that need to transport abrasive material in aqueous medium, causes inner wear of centrifugal pumps, mainly in the impellers. This problem is observed in mineral mining and processing industries. Due to its large territory, Brazil has a great diversity of mineral resources. According to the DNPM (Departamento Nacional de Produção Mineral), mineral production covered over 70 materials in 2011, highlighting niobium and tantalum, which represents 97% and 18.4% of the global production, respectively. In Brazil, extraction of magnetite, chrysotile, bauxite, iron ore, and graphite are among the three largest in the world (DNPM, 2012). Therefore, mining companies spend much of their financial resources in the mechanical maintenance of their equipments, especially in conserving and replacing centrifugal pumps, casing, and impellers. The aim of this work is to design and develop alternative wear-resistant impellers. Those prototypes will be compatible to commercial pumps to facilitate the replacement. Preliminary tests demonstrated that the bladeless impellers designed so far have five times greater durability than the standard ones. However, important parameters such as pressure and flow have not been quantified yet. It is expected that this study will contribute towards the mining industries providing new information and impellers that efficiently replace the standard ones, beyond reducing the maintenance and the costs in the ore pulp pumping.*

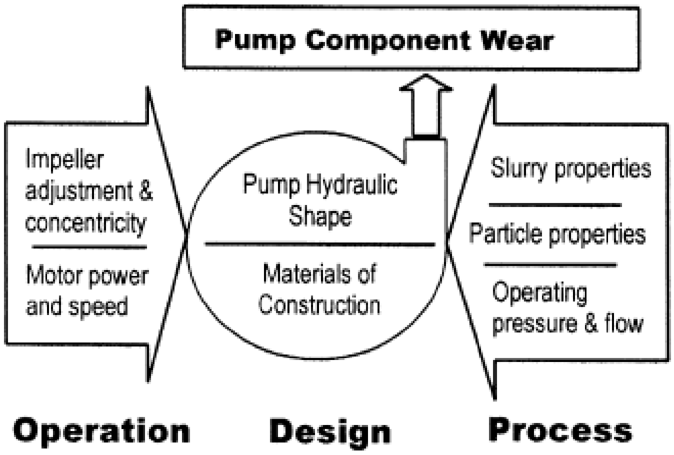
Keywords*: bladeless impeller, pump disc, abrasive fluids.*

1. INTRODUCTION

Centrifugal pumps are usually used by mineral processing companies to transport the ore pulp from the crushing plant to the obtainment of the final product. However, those companies report high rates of wear in impellers and in the pumps' casing, representing up to 10% of total maintenance costs per year (Pereira, 2012).

The pulp must be transported faster than the critical speed to avoid sedimentation of solid particles, which increases the wear out of impellers and casing. Figure 1A details the wear of pump components due to the pumping of an abrasive fluid and Figure 1B the main factors responsible for this issue.

A

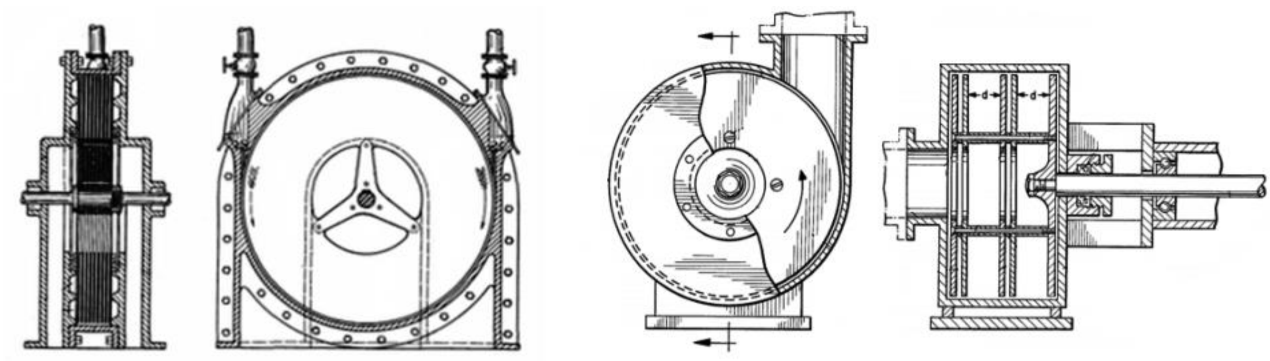


B

Figure 1. Wear in pump impellers (Source: Pereira, 2012) (A). Factors affecting wear life in centrifugal slurry pump (Source: Walker, 1999 *apud* Walker & Bodkin, 2000) (B).

This work aims to substitute standard impellers by bladeless ones. The study started in 2012 after a technical visit in a gold mining industry, in which the pumps' wear problem was reported. So far, studies concerning the wear of pump components have been, in general, limited to the materials used to manufacture the components or merely to their coating. Bladeless impellers were considered after a literature review, which is shortly presented.

In 1913, Nicolas Tesla described a flow machine (pump or turbine) in which the impeller was made of concentric discs. In those discs, fluids gained energy by viscous drag (Patent 1061142). In the same year, Tesla also published Patent 1061206, describing a disc turbine (Figure 2).



A B

Figure 2. Disc turbine: proposed by Tesla in 1913 (A); Gurth (1982) (B).

Many patents were registered after the Tesla Turbine, such as Durant (1977) and Gurth (1982). The later described a "Method and Apparatus for Pumping Large Solid Articles" (US patent 4,335,994) and in 1988 presented three types of impellers without blades.

Therefore, based on mentioned knowledge, companies started pioneer projects involving manufacture of centrifugal pumps that use impellers without blades. One example is the company Discflo (2013) that began to develop low power pumps with bladeless impellers. According to the company's website, this impeller has been employed in several applications, mainly in the pumping of abrasive/viscous fluids. The main characteristic of those pumps is their longer lifetime compared to centrifugal pumps. Nevertheless, it is also known that the output of those devices is lower than the output of centrifugal pumps. Discflo develops pumps that use disc impellers with up to 20 inches diameter, i.e., smaller than the pumps needed in the mining process.

A literature review evidenced the use of disc pumps in the pumping of abrasive fluids and of fluids with high viscosity, as well as in the pumping of fruits, vegetables, live fish and blood, without causing them any damage (Gurth, 1990; Discflo, 2013). Disc pumps can also be used in the pumping of intracorporeal blood (Dorman et al., 1966 *apud* Barbosa, 1992; Discflo, 2013).

2. METHODOLOGY

For preliminary tests, an experimental bench was set up in the Laboratório de Transferência de Calor e Massa (LTCM) (Figure 3). The fluid used in the trials was a mixture of 1.1 kg of silicon carbide in 11 liters of water. The mixture was prepared to accelerate the wearing process during pumping. The abrasive material used had hardness between 9 and 10 Mohs, emphasizing that the highest hardness known is of 10 Mohs (diamond). Consulting Wilson et al. (2006) it was possible to calculate the mixture density, resulting in a fluid with 1.027 kg m^{-3}.

To build the experimental bench, 1''-PVC pipes and fittings were used. PVC was preferred due to its low cost and easy assembly. Pump used in the research had an electric motor of ¾ CV working in 3500rpm.

A

B

C

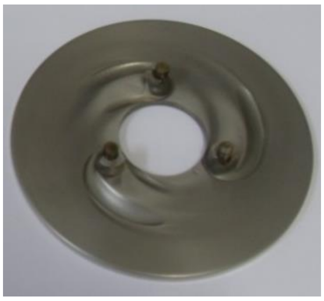
Figure 3. Experimental bench used in the preliminary tests (A).Standard impeller (B) and Bladeless impeller (prototype 1) (C).

Some impellers are shown in the images that follow (Figures 4A-F), before and after the tests. Wear lifetime, in hours, is also presented.

A

B

C



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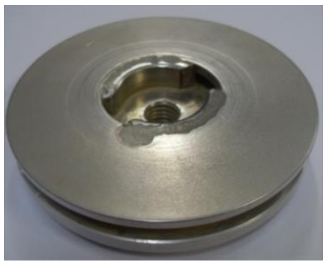


F

Figure 4. Semi open standard impeller (A). Disc impeller with cylindrical spacers in the middle of the disc (prototype 1) (B). Disc impeller with cylindrical spacers near the disc outer radius (prototype 2) (C). Disc impeller with cylindrical spacers near the disc internal radius (prototype 3) (D). Disc impeller with the union in the center of the impeller (prototype 4) (E). Disc impeller with robust spacers (prototype 5) (F).

3. RESULTS AND DISCUSSION

The results of preliminary tests are showed in Figure 5.

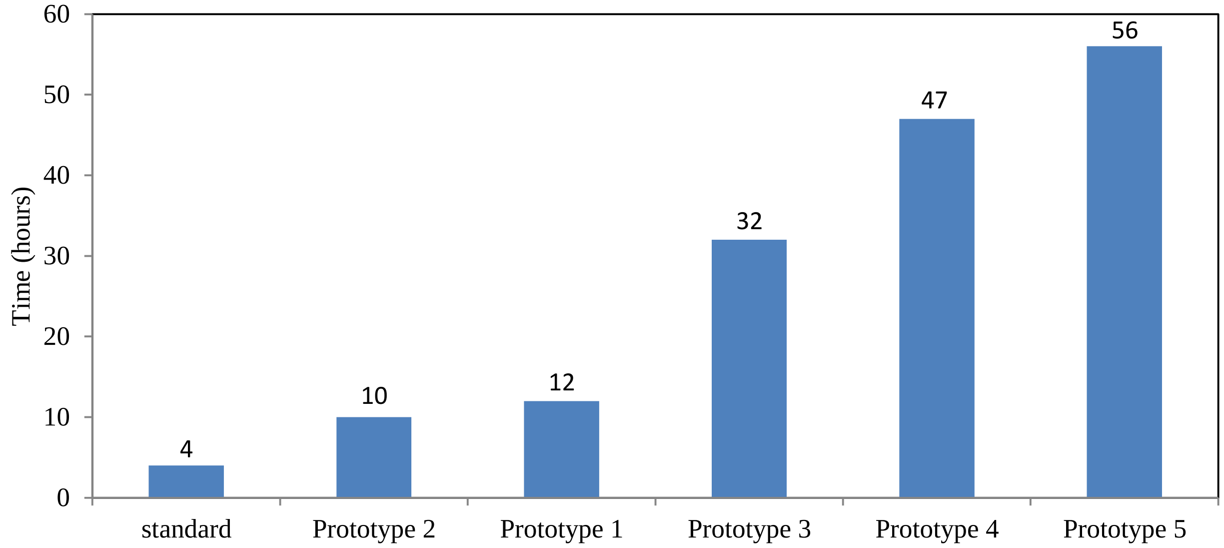


Figure 5. Lifetime of studied impellers.

The results shown in Figure 5 indicate that bladeless impellers can be used longer to pump mineral pulp due to higher lifetime and, therefore, can lead to reduction of maintenance costs. However, to confirm these information, a new experimental bench was projected (Figure 6). This new bench had a 1CV water pump, an electromagnetic flowmeter, a pressure sensor with diaphragm seal, and pinch valves, allowing pressure and flow measurements of liquids with abrasive particles. Data was acquired using Agilent 34970A.

A B C

Figure 6. Project of the new experimental bench (A). Experimental bench at LTCM (B). Multiple-disc impeller designed in LTCM to BC-92T1 pump (C).

Figure 6C shows disc impeller designed to replace the standard BC-92T1impeller. The impeller has multiple discs to improve performance. This work studied the performance curves of the impellers (standard and some prototypes) that had previously showed better performance, and the influence of the distance between the discs.

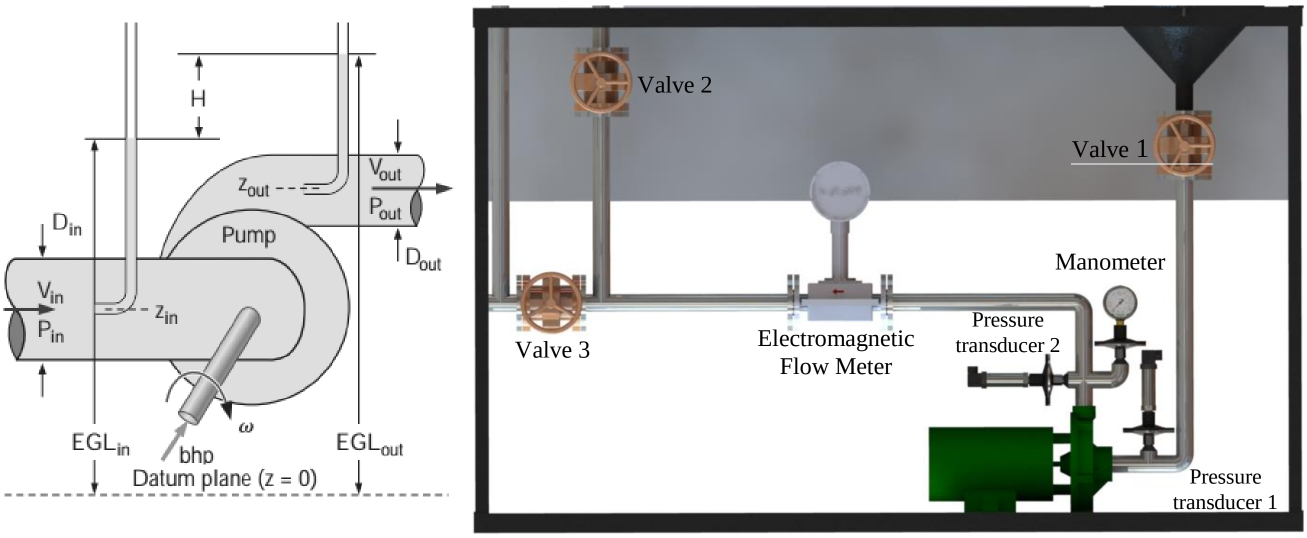
The bench was used to make the characteristic curves of some impellers used in the tests, The pump performance is characterized by its net head (equation 1),

$$H = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + z\right)_{out} - \left(\frac{P}{\rho g} + \frac{V^2}{2g} + z\right)_{in} \quad (1)$$

Where P is the pressure, V the speed, z is the vertical distance, ρ the fluid density and g the gravity. For the special cases $D_{out} = D_{in}$ and the difference in elevation between the inlet and the outlet of the pump is negligible. Therefore, the equation reduces to

$$H = \frac{P_{out} - P_{in}}{\rho g} \quad (2)$$

Figure 7 shows the scheme used to calculate the characteristic curve of the pump.



A B

Figure 7. Net head (H) is defined as the change in Bernoulli head between the inlet and outlet of the pump (A) (Adapted from Çengel, 2015); Bench details (B).

The maximum volume flow rate through a pump occurs when its net head is zero (free delivery). The free delivery condition is achieved when there is no flow restriction at the pump inlet or outlet, meaning that valves 1 and 2 are totally opened. To get other intermediate points of the performance curve it is necessary to gradually close the valve 2 and calculate H values using Eq. 2. The other extreme point, called shutoff head, is the net head that occurs when the volume flow rate is zero (valve 2 totally closed).

The impellers tested were: the standard (closed impeller) to assess the bench; the closed impeller without the blades (these were machined with a cutting disc); the semi open impeller used in the preliminary tests; and, finally, the three-disc impeller developed in LTCM.

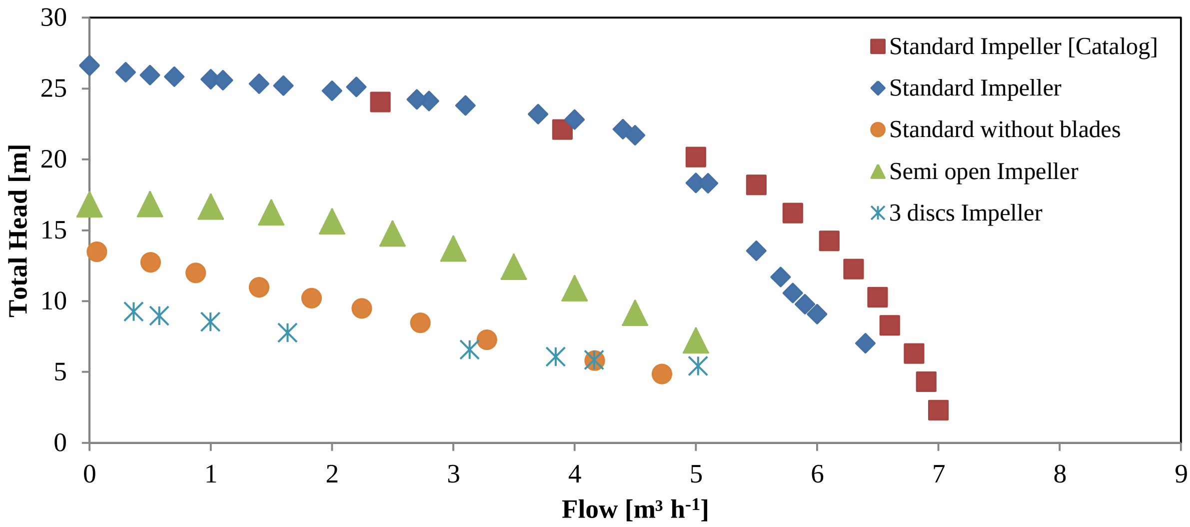


Figure 8. Performance curve of the studied impellers.

Wear tests were performed using an abrasive fluid composed of water and silicon carbide (14 mesh, maximum diameter of 1.41 mm). The bench has a capacity of 50 liters of water, considering pipeline and reservoir. 2.5 kg of abrasive were added. The test results are shown in Figure 9.

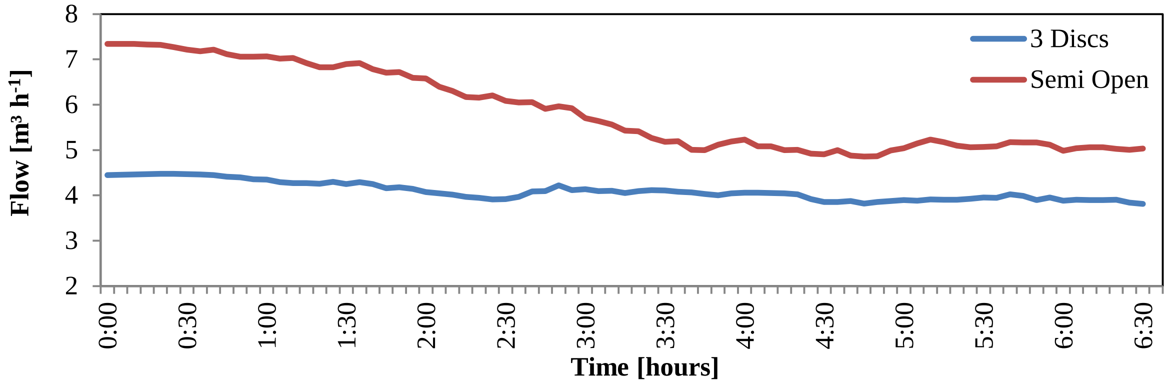


Figure 9. Flow versus time.

Figure 9 shows the flow of the two tested impellers. It can be observed a stable flow behavior for the disc impeller with a slight decrease at two hours and thirty minutes. The semi open impeller, on the other hand, had a 30% flow decrease during the first three hours, remaining practically constant until the end of test.

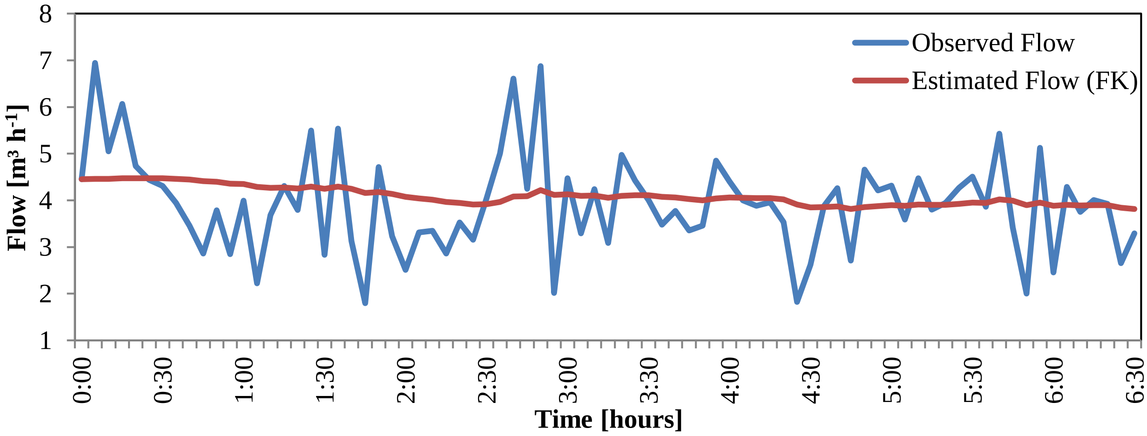


Figure 10. Flow measurements with (red line) and without (blue line) Kalman filter.

According to Molina (2008), bubbles or suspended solids in fluid imply high levels of noise on electromagnetic sensors. In this study, Kalman filter was used to filter the data and estimate the real value of the fluid flow. Some experiments are being conducted to verify the Kalman filter efficiency in this application. Figure 10 shows observed and estimated values.

The pressure sensors have the diaphragm seal to protect them from the abrasive fluid. Figure 11 shows the differential pressure of semi open and disc impellers.

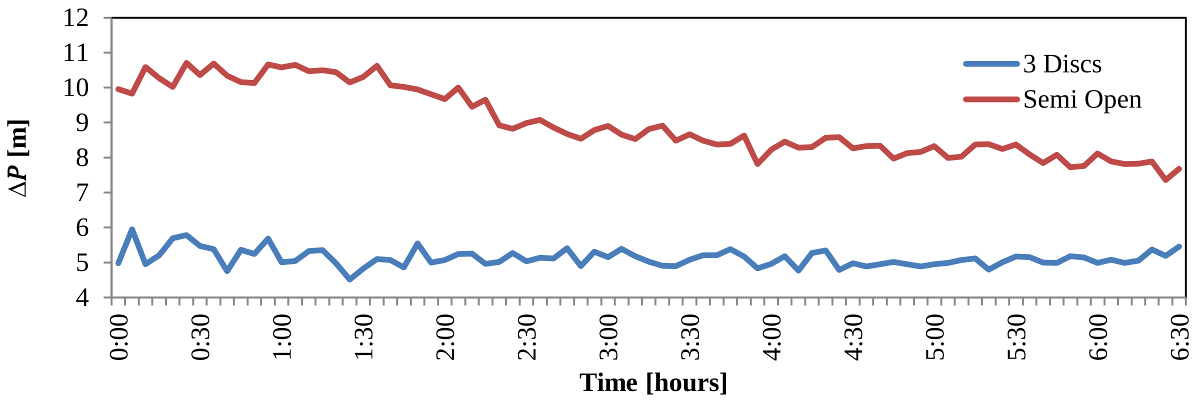


Figure 11. Differential pressure versus time.

The disc impeller pressure had a small loss compared to semi open impeller. Such values can be analyzed in Table 1.

Table 1. Flow values, differential pressure, and respective percentage of reduction.

Time (hours)	Semi Open				3-Disc Impeller			
	Flow [m³ h⁻¹]	Reduction [%]	ΔPressure [m]	Reduction [%]	Flow [m³ h⁻¹]	Reduction [%]	ΔPressure [m]	Reduction [%]
0:00 – 0:30	7.31	0	10.25	0	4.46	0	5.43	0
3:30 – 4:00	5.13	29.82	8.37	18.34	4.06	8.97	5.12	5.71
6:00 – 6:30	5.02	31.33	7.79	24.00	3.85	5.17	5.16	4.97

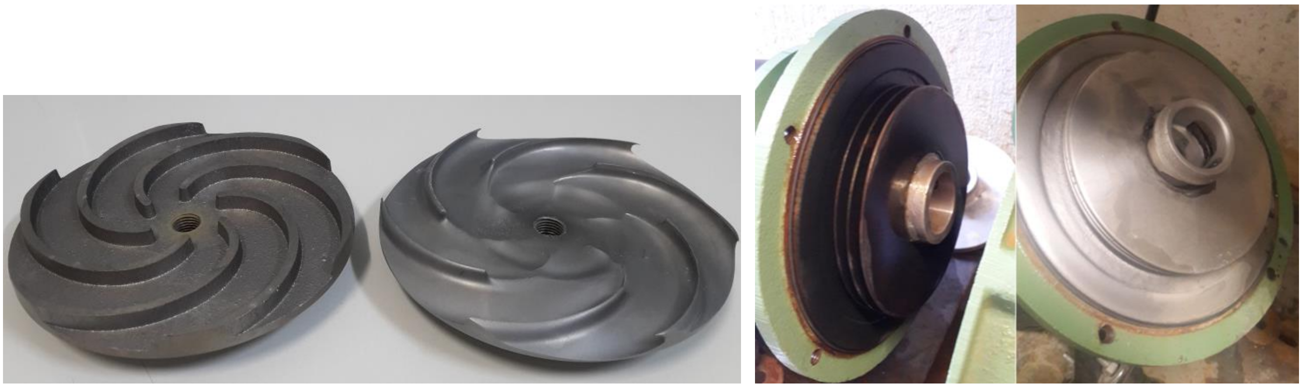
Table 1 contains the flow and pressure values for the two analyzed impellers, as well as the percentage reduction of each impeller as a time function. Data were acquired at 5-minute intervals, so the flow and pressures shown in the table are the mean of the data based at 30-minute intervals.

Pressure and flow reduction for the semi open impeller was five and six-folds higher than the ones of the 3-disc impeller, respectively (Table 2). The increase observed in the pressure of the disc impeller after the third hour was due to the displacement of the discs from the base, since they were fixed with epoxy glue. The current impellers prototypes are mounted by interference.

Table 2. Semi open and disc impeller comparative.

	Pressure Reduction	Flow reduction
Semi Open	24.00%	31.33%
3-Disc Impeller	4.97%	5.17%
Reduction fold	4.83	6.06

Figure 12 shows the wear of the semi open impeller blades and the disc impeller defect at the end of the test (6.5 hours of pumping). The semi open impeller wear rate was of 30.6% while the disc impeller wear rate was of 10.5%. In other words, the wear rate of the disc impeller was three times lower than semi open impeller.



A B

Figure 12. Impellers before and after the test: semi open impeller (A) and impeller discs (B).

4. CONCLUSIONS

Currently, companies invest lots of money in pumps' maintenance. This reality calls for the development of new technologies. The use of disc impellers to pump abrasive fluids is not widely adopted due to its recent release on the market coupled to its high cost. Therefore, the impeller designed in this study can potentially replace conventional impellers once shows lower wear rate and, as a consequence, demands less maintenance. Besides, it has lower flow and pressure reductions during pumping, desirable characteristics for mining processes.

5. ACKNOWLEDGEMENTS

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