Influence of hydraulic components wear on the performance of a sewage pump

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Abstract. User requirements for sewage pumps primarily include reliability, which depends on the pump design and timely maintenance, as well as efficiency. For sewage pumps, wear on flow components significantly impacts performance over time, causing even highly efficient pumps to lose efficiency quickly.

This paper presents a comparison of the performance and flow analysis of a two-blade sewage centrifugal pump before and after renovation. The primary research objects were the impeller and the shroud seal. 3D optical scanning and reverse engineering were used to capture the real geometric parameters of the pump's flowing parts. The investigation included numerical simulations for different flow rates, as well as physical experiments on a test stand.

The most damaged areas were the leading and trailing edges of the impeller and the shroud seal. The pump was renovated by replacing the damaged hydraulic components with new ones. Numerical analysis revealed the structure of the flow, the locations and distribution of losses, and areas of erosion. Testing showed that the pump's efficiency increased from 44% to 68%, approaching its nominal efficiency. Furthermore, the pump's flow rate at the BEP increased from 390 m³/h to 506 m³/h. Volumetric efficiency increased from 70% to 95%, and hydraulic efficiency increased only from 68% to 73%.

These results demonstrate that wear of shroud seal has a more significant influence on pump operating parameters and efficiency while increasing energy consumption, than wear of the impeller.

Keywords: Two-Blade Impeller, Two-channel Impeller, Volute, Centrifugal Pump, Wear Flowing Parts, Shroud Seal.

1 Introduction

Pumps, though not always noticeable in our industrialized world, play a vital role in various applications. Sewage pumps, in particular, are essential for the efficient transport of sewage and sludge in both municipal and industrial systems. The long-term performance of these pumps is influenced by various operational factors, with hydraulic component wear being one of the most significant. Wear on key components, such as

impellers, shroud seals, and casings, alters the pump's hydraulic characteristics, leading to reduced efficiency, increased energy consumption, and potential failures.

According to the European directive, final energy consumption in the EU should be reduced by 11.7% by 2030 [1]. That is why the efficient operation of pumps in wastewater treatment facilities is crucial. Timely maintenance one of the key factors in maintaining high pump efficiency and helps prevent failures that lead to costly downtime or damage. Component wear largely depends on environmental conditions. Sewage or contaminated water accelerate degradation, especially in hydraulic components. Corrosion and erosion increase surface roughness, leading to higher friction losses and reduced hydraulic energy conversion efficiency. Additionally, wear of the wear ring increases clearances, promoting recirculation and further efficiency losses [2].

The most critical selection parameters for a new installation are performance characteristics, the size of particles passing through the pump, and the erosion wear of the sewage pump [3]. Yang et al.[4] investigated the influence of particle density on pump characteristics and the distribution of particle concentration on the volute surface. When the density of solid particles is greater than that of water, the solid-phase concentration on the surface increases, leading to greater wear. Pokharel et al. [5] presented various wear mechanisms and their causes, with adhesive, abrasive, cavitation, corrosive, erosive, fatigue, and fretting wear having the greatest impact on pump components. Sewage pumps are most susceptible to erosive, corrosive, and cavitation.

Singh [6] analyzed various materials for impellers. Stainless steel is preferable for pumps used in contaminated liquids or hydraulic transport due to its relatively lower brittleness, which is an advantage over cast iron. Additionally, impellers can be coated with a special protective layer to enhance durability. Sharif et al. [7] emphasized that fluid contamination includes both solid particles and chemicals. In cast iron sewage pumps with a spheroidal graphite layer, corrosion rates rise significantly in acidic environments. Choosing harder materials improves wear resistance, as hardness and wear resistance are generally linearly related within the same metal type.

Lipej et al. [8] compared the results of pump numerical simulation with and without considering surface roughness. The model that accounted for roughness achieved better convergence. Li et al. [9] also incorporated roughness in their simulation but did not outline the differences in results based on the adopted roughness value. He et al. [10] demonstrated that when wall roughness was below a critical value, it had a significant impact on pump performance, including head, efficiency, and shaft power. Wall roughness had a greater effect on efficiency and disk friction power loss than on head and hydraulic power loss. He et al. [11] also compared the performance parameters of a multistage centrifugal pump with different roughness values. Specifying roughness settings without performing their measurements can even worsen calculation results compared to those with a correct roughness value. As flow velocity increases, the negative impact of surface roughness on pressure and efficiency becomes more pronounced. He et al. [12] compared pump performance and flow patterns at different roughness values, finding a significant effect. However, using the same roughness for all surfaces did not reflect real pumps. Roughness impacted mechanical power more than hydraulic power, and numerical simulations exceeded experimental results.

The performance and reliability of sewage pumps are significantly influenced by the wear of their hydraulic components. Erosion is most pronounced at points where fluid changes direction or reaches high velocity. Shroud wear ring and its impact on pump performance are rarely studied. This study investigates the effect of hydraulic component wear, particularly shroud wear ring , on sewage pump performance, focusing on changes in flow structure, head, flow rate, efficiency, and power consumption. By analysing new and worn components, this research aims to provide insights into the degradation affecting pump performance and to establish predictive models for maintenance planning. The findings aim to improve pump operation, predict maintenance needs, and enhance wastewater system reliability while reducing costs.

2 Object of Research

The object of the current research is a sewage submersible pump (see Fig. 1 a) used in power plants. The operating medium is dirty water with dust, with a slurry density of 2070–2252 kg/m³, at temperature range of 70–90 °C, and a pH of 7.5–9.0. The mean particle diameter is 0.06 mm, with a maximum of 0.35 mm. This is an extremely harsh environment, which leads to accelerated wear of the pump's operating and hydraulic components.

The nominal pump operation parameters are: head H = 12.4 m, flow rate Q_{nom} = 560 m³/h, shaft rotational speed n = 1446 rpm, nominal electrical power of 28 kW, specific speed n_q = 84. The impeller's outer diameter is D_2 = 292 (min 176) mm, with z = 2 blades. The pump (see Fig. 1) was analyzed in two conditions: repaired with new impeller and wear ring and worn after extended operation. The focus was on the impeller (see Fig. 1 b-d), and the shroud seal formed by the gap between the impeller and wear ring, which exhibited significant hydro-abrasive wear. Substantial wear was observed on the impeller blades, particularly on the leading and trailing edges near the shroud. This wear was likely caused by high linear velocity and centrifugal forces acting on solid particles (see Fig. 1b–d), leading to the formation of local vortices. The reduction in the impeller's mass is approximately 3.5%. Additionally, the front seal showed considerable erosion of surfaces and sharp corners. Both the impeller and casing are made of grey cast iron EN-GJL-250.

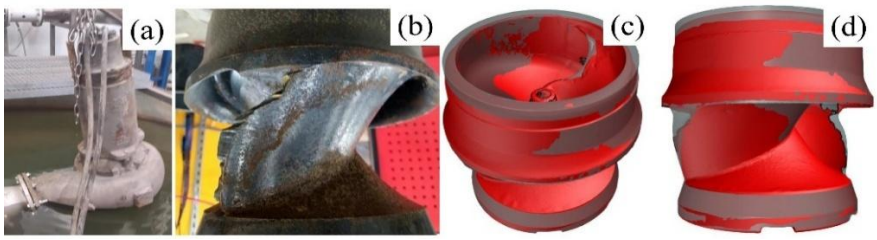


Fig. 1 Investigated sewage pump: a) pump; b) impeller; c) and d) comparison of forms of worn impeller (indicated in red) and new impeller (indicated in grey)

3 Research Methodology

3.1 Experimental Research

The main goal of the tests was to obtain the actual performance characteristics of the pump unit and demonstrate the impact of wetted parts wear on the pump's hydraulic and energy parameters. The experimental stand (see Fig. 2) included a proprietary SCADA-based system for graphical test visualization and a 75 kW inverter. The pumping medium used was water at a temperature of 16°C. Two performance tests were conducted before and after the repair. Each covering a minimum of 14 operating points. The pump testing followed the ISO 9906: 2012 standard.



Fig. 2 Experimental stand of submersible pump: 1 – test tank simulating a well; 2 – discharge throttling valve; 3 – discharge pipe; 4 – electromagnetic flowmeter; 5 – pressure sensors; 6 – manometer; 7 – frequency converter; 8 – guides for submersible pumps coupling foot

3.2 Numerical Studies

An ATOS 3D scanner (0.05 mm precision) captured the pump components' geometry, generating a high-density point cloud. Inverse and 3D modelling were used to create the metal wall and fluid domains of the pump. Numerical simulations were the primary research method. The computational fluid domain model included the water inlet, a two-bladed impeller, volute, front sidewall gap with a shroud seal, and the outlet pipe with an elbow (see Fig. 3 a). The first stage evaluated the pump after repairs, excluding the fluid domain of the front sidewall gap with the shroud seal. The second stage examined the pump before repairs, also excluding this fluid domain. The third and fourth stages analyzed the pump after and before repairs, respectively, including the fluid domain of the front sidewall gap with the shroud seal. This approach provided a better understanding of pump performance and flow characteristics within the impeller, the shroud seal, and their interaction.

The prepared 3D models were discretized using a tetrahedral mesh for the inlet water body, impeller, volute, and front sidewall gap with shroud seals, while a swept mesh was applied to the outlet pipe body. The meshing process was performed using ANSYS Meshing software. The mesh element sizes were determined based on a mesh

sensitivity study (see Fig. 3 b). Near solid boundaries, prismatic element layers were incorporated to accurately capture boundary layer effects. The Y-plus value ranged from 10 to 100. The total number of elements for the pump's fluid domain, excluding the front sidewall gap, was 18 million. The front sidewall gap contained 13 million elements with a new shroud seal and 10 million with a worn seal. Additionally, all four models were simulated with measured surface roughness parameters.

The sewage pump's operation was simulated using ANSYS Fluent with a steady-state approach utilising the Reynolds-Averaged Navier-Stokes (RANS) equations and the standard k-ε Realizable turbulence model [12, 13]. Boundary conditions included total pressure (TP) at the inlet and mass flow rate at the outlet. Simulations covered 0.3 to 1.2 times the nominal flow rate (Q_{nom}) using clean water at 16°C. An unsteady simulation was conducted to determine the impeller position relative to the spiral tongue and validate the steady-state results.

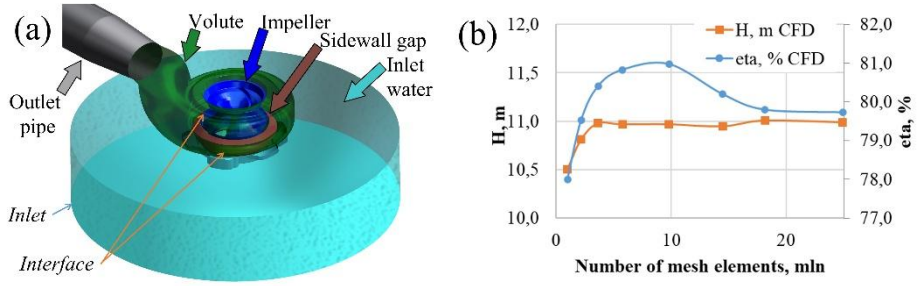


Fig. 3 Computational fluid dynamics (CFD): a) the computational model of the sewage pump; b) mesh sensitivity study

4 Research Results and Their Analysis

4.1 Comparison Repaired and Worn Pump Characteristics

The test results indicate that the worn pump operates significantly below its nominal performance characteristics (see Fig. 4). The head decreased to 9 m, the flow rate dropped to 390 m³/h, the pump unit efficiency decreased to 44%, and the power consumption decreased to 21.4 kW at the best efficiency point (BEP). After the overhaul, a new operating point for the pump unit was achieved (see Fig. 4). The head increased to 12.2 m (by 35%) at a flow rate of 506 m³/h (increased by 30%), with a power consumption of 27.4 kW (increased by 28%) and a pump unit efficiency of 68% (increased by 55%) at new BEP. Following the overhaul, the device's performance characteristics fell within the acceptable tolerance range.

The H-Q curve (new, CFD) (see Fig. 4) for the repaired pump matches experimental data, while the worn pump's (worn, CFD) does not. Including the front shroud seal improves H-Q curve, aligning within ±4% at BEP flow rate (Q_{BEP}). This is attributed to the significant losses in the front shroud seal and changes in volumetric efficiency (see Fig. 5). Surprisingly, impeller wear does not cause significant losses in hydraulic

efficiency, resulting in a maximum additional loss of only 1 kW (5% losses), while seal-related losses can reach up to 9.5 kW (47% losses) (see Fig. 5c).

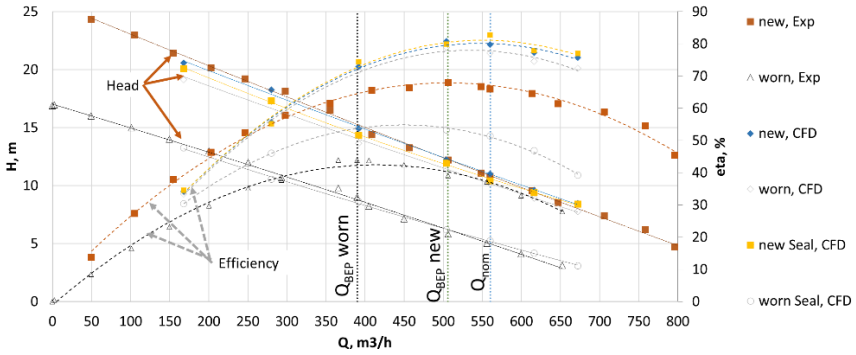


Fig. 4 Comparative characteristics of experiment (Exp) and numerical simulation (CFD) results – head and efficiency curves at numerical model without roughness

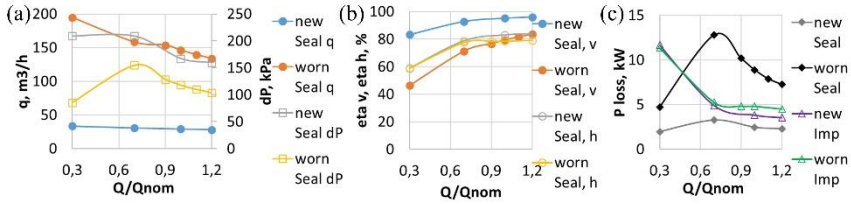


Fig. 5 Comparative characteristics of different clearance in shroud seal at model with roughness: a) leakage (q) and pressure drop (dp); b) volumetric (eta v) and hydraulic (eta h) efficiency; c) energy losses in shroud seal and impeller

The CFD efficiency (see Fig. 4) exceeds experimental results due to model simplifications. Adding roughness improved accuracy, reducing the efficiency gap to 10% for the worn pump and 5% for the repaired one. Additionally, better matching of the Q_{BEP} value and the H-Q curve curvature with experimental results was achieved, with a deviation of 5% at Q_{BEP}.

4.2 Comparison influence of worn and new impeller

The TP profile in the impeller for both the repaired and worn pumps does not differ significantly at Q_{nom}, but at Q_{BEP}, which is smaller than Q_{nom}, the worn impeller exhibits noticeably higher TP at the outlet (about 15 kPa) and front shroud (about 30 kPa) (see Fig. 6). A similar trend is observed for the velocity profile (see Fig. 7 a-c). The zone of increased speed near the impeller front shroud, caused by centrifugal force, is clearly visible, which results in an increase in total pressure. The distribution in the volute (see Fig. 7 d-f) is very uneven at Q_{nom}, with low velocity approximately 1 m/s observed near the tongue. The distribution becomes more uniform in the zone from 0º to 90º, where the speed is close to 5 m/s, which is the average value in volute at Q_{BEP}. This is due to the change in flow rate. The biggest difference is observed at Q_{nom} and Q_{BEP}.

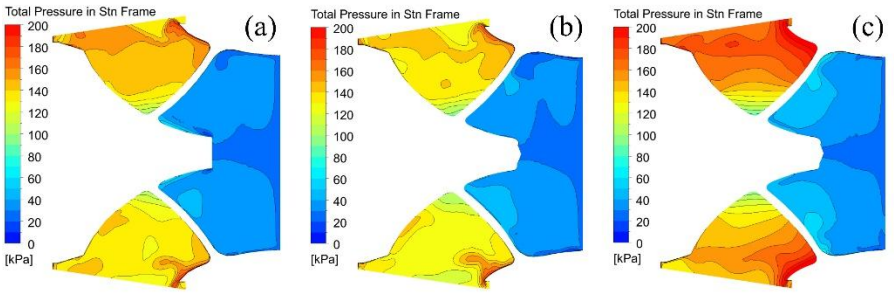


Fig. 6 Total pressure distribution in the impeller at pump model without shroud seal: a) repaired pump at the Q_{nom}; b) worn pump at the Q_{nom}; c) worn pump at the Q_{BEP}

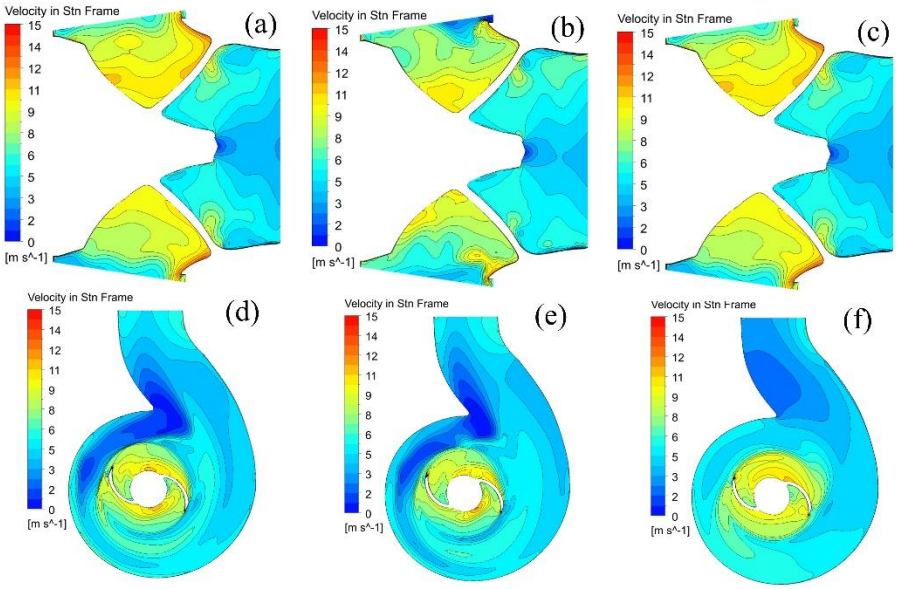


Fig. 7 Velocity distribution at pump model without shroud seal: a) new impeller at the Q_{nom}; b) worn impeller at the Q_{nom}; c) worn impeller at the Q_{BEP}; d) new impeller and volute at the Q_{nom}; f) worn impeller and volute at the Q_{nom}; e) worn impeller and volute at the Q_{BEP}

4.3 Impact of shroud seal

Adding fluid domain of front sidewall gap with shroud seal to the model significantly alters the TP and velocity distribution, especially in the worn pump (see Fig. 8) In the repaired pump, the addition of shroud seal reduces the TP difference within the impeller by increasing TP by 50 kPa near the front shroud wall before the blades suction side and decreasing TP by 20 kPa near the front shroud wall after the blade pressure side. Significant changes in TP distribution are visible in the worn pump. Volumetric losses are substantial. The flow from shroud forms a jet that dramatically alters the pressure and velocity fields, with the structure and value being influenced by flow rate.

Specifically, TP decreases by 10 kPa at the main part of the impeller inlet, but increases by 70 kPa in the jet zone at flow rate Q_{nom}, and even by 90 kPa at Q_{BEP}. At the impeller outlet, there is a pressure increase of approximately 10 kPa at Q_{nom} and a decrease of about 35 kPa at Q_{BEP}, except in the zone near the front shroud of the impeller, just after the blade's pressure side.

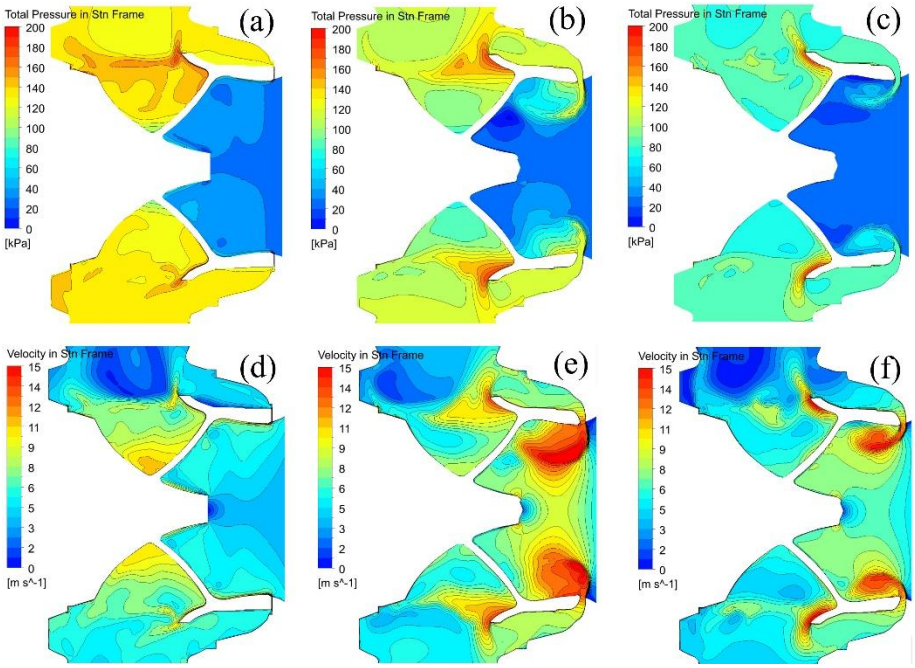


Fig. 8 Flow distribution in pump model with front shroud seal: a) TP – repaired pump at the Q_{nom}; b) TP – worn pump at the $Q_{nom;}$; c) TP – worn pump at the Q_{BEP}; (d) Velocity – repaired pump at the Q_{nom}; e) Velocity – worn pump at the Q_{nom}; f) Velocity – worn pump at the Q_{BEP}

The wear of the shroud seal increased the gap by 8 times (see Fig. 9). As a result, the flow structure is completely changed. In the repaired pump, the TP in the front sidewall gap remains relatively stable, and the drop in the front seal is quite significant – 28% of head at Q_{nom}. In contrast, in the worn pump, the TP gradually drops through the front sidewall gap and the front seal. This accounts for just 7% of the head at Q_{nom}, which means that the remaining pressure losses contributing to the reduction in pump head occur in the front sidewall gap and the impeller, as evidenced by flow disturbances. The velocity follows a similar trend. In the repaired pump, the velocity in the gap increases rapidly to 8 m/s due to the rotation of the rotating component (RK). A slower increase, up to 5 m/s, is also observed in the worn seal, caused by a change in the channel cross-section. At the same time, the flow rate through the gap is 5–6 times higher across the entire operating range, indicating that volumetric losses are more significant than pressure losses.

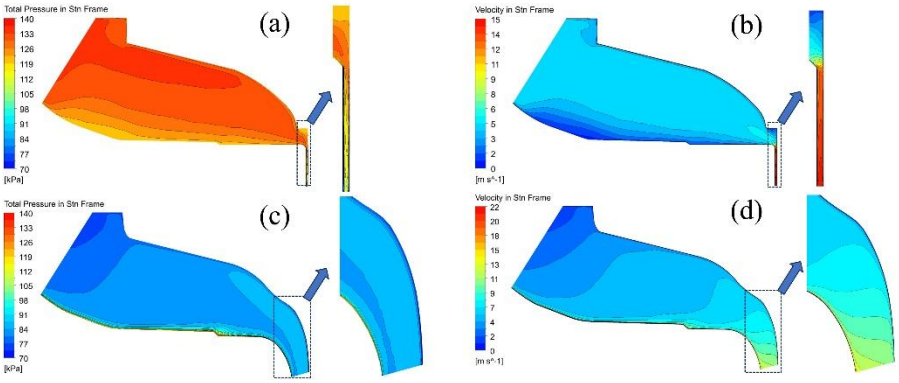


Fig. 9 Flow distribution in the front side gap and shroud seal: a) TP, repaired pump at the Q_{nom}; b) Velocity, repaired pump at the Q_{nom}; c) TP, worn pump at the Q_{nom}; d) Velocity, worn pump at the Q_{nom}

5 Conclusions

The article compares the performance and flow structure of a sewage two-blade pump in repaired and worn conditions. It compares the operation curves obtained from numerical simulations with the test pump performance. An analysis of the flow structure was carried out at different flow rates and roughness levels. Wear of hydraulic components in sewage pumps is a critical factor influencing their operation:

- Erosion of wetted parts over time significantly reduces head, flow rate, and efficiency, causing performance to drop below nominal characteristics.
- The repaired pump, based on experimental results, achieved a higher head (more by 3.2 m), flow rate (more by 116 m³/h), power consumption (more by 6 kW), and efficiency (more by 24%), bringing performance within acceptable tolerance ranges.
- The front shroud seal plays a critical role in hydraulic efficiency. Wear in the seal leads to significant losses by altering the flow structure. The numerical model that includes the front seal shows improved agreement with experimental data across all operational parameters. Repairing the pump resulted in a 25% increase in volumetric efficiency and a 5% increase in hydraulic efficiency.
- The numerical model without roughness shows convergence with experimental results for the H-Q curves, but not for efficiency and power. Including roughness improves the results, with max deviation of 5% for repaired and 10% for worn pump.
- Comparison of the distribution of TP and velocity in the pump cross-sections indicates a small influence from the new and worn impeller and volute on the flow structure. The most significant influence is caused by wear of the shroud seal.
- The study highlights the need for regular maintenance of key components like the impeller and shroud seal to ensure optimal pump performance.

- The results obtained confirm that advanced numerical simulation techniques are essential for enhancing efficiency predictions and ensuring accurate assessments of pump behaviour.

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