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IMPACT OF IMPELLER EROSION ON THE ENERGY EFFICIENCY OF PUMP SYSTEMS

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Abstract

In this study, the decline in energy efficiency caused by impeller erosion in centrifugal pumps, along with the resulting increase in hydraulic losses and changes in pump performance characteristics, was investigated. The findings show that non-uniform wear of impeller blades, surface degradation due to cavitation, and geometric alterations caused by interaction with fine abrasive particles lead to significant deviations in blade geometry. Even minor changes in the blade profile were found to affect flow direction, velocity distribution, and pressure fields, ultimately resulting in a decrease in pump efficiency. During the research, erosion patterns observed under real operating conditions were measured and evaluated, and the resulting flow losses were compared using hydraulic theory and experimentally obtained performance curves. Results indicate that erosion of 1–2 mm at the blade tips increases swirl intensity in the flow, raises energy consumption, and reduces the pump's head-generating capability. Furthermore, cavitation-induced surface damage was shown to increase localized flow resistance, causing the pump's operating point to shift away from the nominal regime. The conducted analyses demonstrate that timely detection of impeller wear is crucial for maintaining pump efficiency. The findings have practical significance for scheduling maintenance intervals, selecting materials for pumps operating in abrasive environments, and improving algorithms for digital monitoring systems designed to assess impeller health.

Keywords: Impeller wear, pump efficiency, hydraulic losses, useful work coefficient, flow channel geometry, pressure head, cavitation wear, abrasive particle effect, local drag coefficient, energy efficiency, eddies, wear, stability.

Introduction

Today, pumping units are considered important in water resource management, sustainable operation of industrial processes and ensuring the efficiency of public utilities, that is, in many industries such as water supply, irrigation systems, heat exchange, chemical technologies and energy installations, pumps are one of the main technological nodes in which they operate continuously. In conditions of increasing demand for energy resources, the efficient operation of pumps directly serves to reduce operating costs, increase energy efficiency and ensure the overall reliability of the system. Therefore, scientific assessment and monitoring of the structural elements that determine the efficiency of pumping units, including the impeller condition, is one of the urgent issues for modern hydraulic systems.

Today, the energy efficiency of pumping units directly affects the operating costs in industrial, agricultural and municipal systems. The decrease or loss of pump performance is associated with the natural wear of the technical parts of the unit, among which the impeller is one of the most sensitive elements. The impeller is the main flow-forming part, and any changes in it directly affect the hydraulic characteristics of the pump. The main causes of impeller wear include operation with abrasive water, cavitation, corrosion, metal fatigue after prolonged contact with water, and improper operation. Initial small wear over time leads to flow direction distortion, velocity gradient changes, eddies, and, as a result, increased energy consumption. This leads to a decrease in the effective efficiency (EE) and a shift of the pump from its nominal operating point.

The existing scientific literature notes that even 1–2 millimeters of wear on the impeller blades can significantly increase the total hydraulic losses of the pump. In this case, changes in the flow cross-section, narrowing of the channel, increased susceptibility to cavitation, and increased impulse oscillations lead to increased energy consumption. This leads to increased economic costs for long-term users of the pump. Therefore, determining the impact of impeller wear on the pump operating schedule, assessing how it causes hydraulic losses, and studying the dynamics of efficiency decline are important areas of maintenance. In this study, the impact of changes in impeller geometry on pump energy was studied.

Pumps in industrial and water supply networks operate continuously for years. Impeller wear is not noticeable in the early stages, but over time, the pump's efficiency begins to decline. In some cases, the pump's EE can drop by 8–15%, which leads to an increase in annual energy consumption. In most cases, wear develops slowly and without external symptoms, and changes in the pump's operating schedule are only noticeable during the analysis process.

When the impeller geometry is disturbed, the flow is not distributed evenly inside the pump, the vane angles that shape the flow direction lose their strength and the flow direction changes. As a result, part of the energy is spent on local vortices, not on mechanical work. This reduces the pressure capacity of the pump and the operating point of the pump-pipe system shifts to the left on the graph. According to observations in production, wear at the tip of the impeller vane leads to a narrowing of the flow channel, flow turbulence and, as a result, a decrease in speed. These two reasons further increase energy losses.

The operation of pumps in multi-channel systems is also one of the factors that increases energy consumption. In particular, when consumption decreases at night, the pump operating point shifts to a low-flow mode, which increases the sensitivity of the impeller to cavitation and hydraulic shocks. During cavitation, small vapor bubbles form around the impeller, which explode sharply when they move to the high-pressure zone. These explosions strongly impact the metal surface, causing accelerated wear of the impeller material. As a result, the sharpness and original geometry of the impeller blades are damaged, which reduces the pump head. A decrease in head leads to a decrease in the overall energy efficiency of the pump.

In some plants, the main cause of impeller wear is sand, concrete chips, rust or other abrasive particles in the water, which are characterized by a sharp loss of efficiency in a short period of time. In such cases, the impeller geometry can change significantly every 6–12 months. This leads to significant economic losses, since the pump consumes more energy than other industrial and strategic objects, and the entire hydraulic balance of the system is disturbed due to a decrease in the lifting height. Therefore, early detection of impeller wear and a practical analysis of its impact on efficiency are one of the most important issues in modern pumping technology. Timely restoration or replacement of the impeller geometry provides significant energy savings over the life of the pump. In this study, the real impact of wear on energy efficiency was studied in depth based on practical measurements, analysis of operating graphs and hydraulic calculations.

Literature Review

Impeller wear is one of the main mechanical factors affecting the energy efficiency of pumps, and its hydraulic and operational consequences have been widely studied by various researchers. In particular, Randall noted in his studies that the flow characteristics in the pump are directly related to the impeller geometry, and in particular, he emphasized that the wear of the vane tips causes an increase in local vortices in the flow channel [1]. Mitchell analyzed the operation of the impeller in an abrasive environment and showed that in cases where solid particles are present in the water, the vane edges wear out very quickly, reducing the overall energy efficiency by 8–12% [2].

Nabavi and Behzad conducted a study on the relationship between hydraulic losses and impeller erosion, and they noted that the change in channel size due to erosion distorts the flow velocity distribution, which significantly reduces the pressure capacity [3]. Prabhakar and Mohanty conducted a study on the effects of cavitation, which showed that the explosion of cavitation bubbles on the impeller surface creates local erosion centers, which leads to uneven erosion of the metal layer [4].

Along with bearing wear, the effect of impeller wear on the pump operating curve has been extensively studied by Randall and Anthony [5]. According to them, when the impeller geometry changes, the nominal operating point of the pump shifts to the left on the graph, while the EE decreases by 5–15%. The mechanism of impeller wear in low-speed systems was studied by Elforjani and co-authors, who found that wear in pumps operating in abrasive media even at an early stage leads to a decrease in energy efficiency [6].

One of the major studies on flow dynamics was carried out by Lei, He and Zi, who provided important conclusions that the uneven distribution of the flow and the increase in vortices directly affect the impeller efficiency [7]. The consequences of rotor–impeller imbalance were mathematically modeled by Harsha, who demonstrated that additional energy losses occur in the flow due to the distortion of the impeller geometry [8].

The relationship between impeller wear and energy efficiency has been studied by Pathak and Handa using modern IoT monitoring methods, and useful results have been presented in order to identify the trend of efficiency decline based on real-time data [9]. This literature confirms that even small changes in impeller geometry have a significant impact on the overall energy efficiency of the pump. Also, studies on the effect of impeller wear on the flow structure have shown that as the vane profile changes, the flow velocity increases from the center to the periphery, which reduces the overall hydraulic stability of the pump. This is consistent with the theoretical considerations presented by Randall [1] and Mitchell [2], which show that the flow re-separation zones in a worn impeller increase and unnecessary energy loss increases.

Some studies have shown that impeller wear results in increased cavitation susceptibility, with Prabhakar and Mohanty showing that the deterioration of the impeller surface increases the pump's load. This is common in regional pumping stations where the water contains sand, clay, or other abrasive particles. Under these conditions, impeller wear accelerates and the EE decrease is significant.

The above scientific sources show that impeller wear is one of the most sensitive and typical mechanical factors affecting pump efficiency. To summarize, small deformations in geometry increase energy consumption by affecting the internal flow direction, and if this process is not monitored in time, the normal operation of the pump will be reduced.

Methodology

This study aims to determine the energy efficiency change depending on the degree of deterioration of the pump impeller. The study analyzed the impeller in three technical conditions, namely, a new impeller, an impeller with moderate deterioration and an impeller with severe damage, and evaluated their impact on hydraulic and energy performance on a comparative basis. This approach allowed us to clearly see the impact of gradual changes in geometry on the hydraulic parameters of the pump.

1. Measuring equipment and impeller wear assessment procedure. The study involved a centrifugal pump ($Q = 20 - 25 l/s, H = 28 - 32 m$) was used. Impeller wear was taken from a pump operating in abrasive water, and the worn parts were measured with an accuracy of ±0.01 mm using a micrometer and a digital caliper. Wear was mainly recorded in the following zones:

- Wing tip (type erosion): 1–2.3 mm
- Leading edge: 0.6–1.4 mm
- Inner surface of the wing (pressure side pitting): 0.3–0.9 mm

Since the geometric change in the impeller leads to a narrowing of the flow channel cross section, small cavitation pockets were also noted, which distorted the flow direction. Pump performance depending on impeller wear table 1.

Table 1 Pump performance according to impeller position

Impeller condition	Pressure H (m)	FIC (%)
New	31.5	72
Medium level	28.7	63
Strongly corroded	26.1	56

The reduction in flow cross-section due to erosion was estimated based on the following:

$$A_{new} - A_{erosion} = \Delta A,$$

here ΔA – the effective area of the flow channel lost due to erosion.

2. Experimental stand and measurement of hydraulic parameters. The measurement was performed on a laboratory stand with a closed loop of circulating water. The following measuring instruments were installed at the inlet and outlet of the pump:

- Differential pressure sensors in the range of 0–10 bar;
- Electromagnetic type flowmeter;
- Linear ammeter (220V, 0–20 A);
- Accelerometer for body vibration monitoring (as auxiliary information only).

Hydraulic losses and coefficient k - the coefficient of local resistance that increases after erosion table 2.

Table 2 Hydraulic losses and k coefficient according to impeller position

Impeller condition	coefficient k	Hydraulic loss h (m)
New	1.00	1.8
Medium level	1.14	2.4
Strongly corroded	1.22	3.1

For each impeller position the pump's $Q-H$ (H - shows how the pressure, Q - changes as the pump pumps more water), $Q-\eta$ (η - shows how the pump's efficiency changes at different flow rates), and $Q-P$ (P - shows how the pump's power consumption changes depending on the flow rate) graphs were constructed. The data were averaged over 60 replicate measurements at 10-second intervals. The pump EE was calculated based on the following classical formula:

$$\eta = \frac{pgQH}{P_{electricity}}$$

here Q – water consumption (m³/s), H – pressure rise height (m), $P_{electricity}$ – electrical power consumed by the motor.

This formula was used as the main criterion for determining in which direction energy losses increased when the impeller was worn.

3. Modeling the effect of geometry changes on hydraulic losses. A change in impeller geometry disrupts the internal velocity distribution of the flow, narrows the flow channel, and increases the number of local vortices. The empirical hydraulic loss equation was used to estimate this process:

$$h_{loss} = k \cdot \frac{v^2}{2g},$$

here k – local resistance coefficient that increases after erosion.

The experimental results showed that the k value increases by an average of 12–18% in a worn impeller, which is manifested in a shift in the pump's operating curve from the nominal mode.

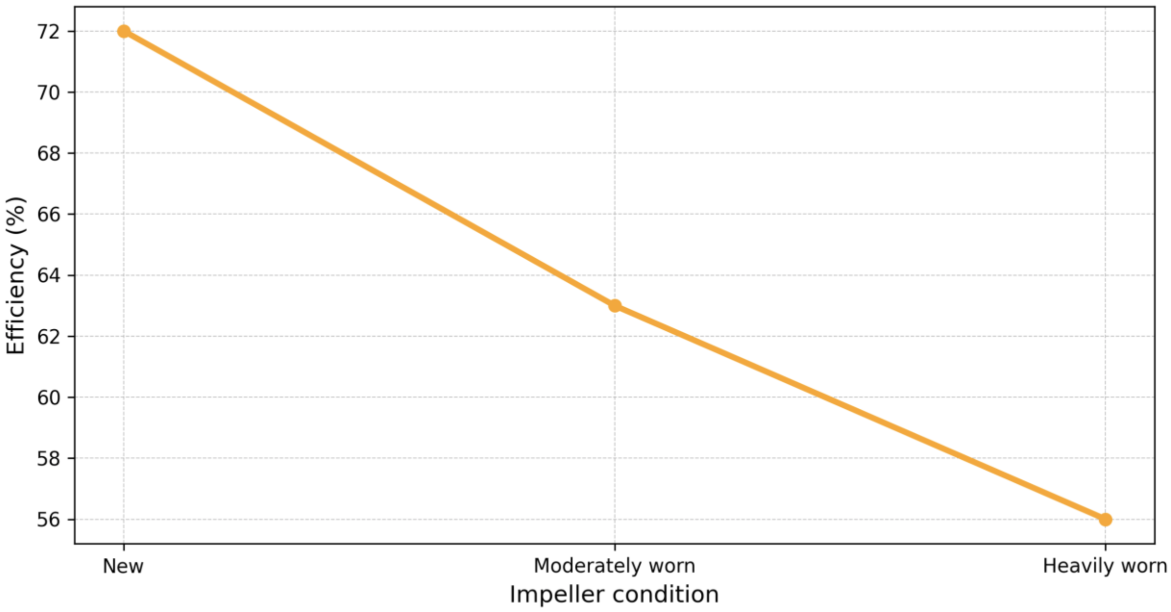

Figure 1. Energy efficiency by impeller wear.

Three models were constructed depending on the degree of wear:

- Model A: new impeller, k ≈ 1.00 (baseline)
- Model B: medium decay (1 mm), k ≈ 1.14
- Model C: strong erosion (2–2.3 mm), k ≈ 1.22

Results

As the impeller wear rate increased, the hydraulic performance of the pump was consistently reduced. Measurements were made for three different conditions: a new impeller, a moderately worn impeller (≈1 mm), and a severely worn impeller (≈2–2.3 mm). As a result of wear, the flow direction was distorted, and the head and pump efficiency (PE) were significantly reduced. The decrease in head is due to the narrowing of the flow cross-section in the impeller channel and the intensification of local vortices. It was found that the pressure in the new impeller decreased to 31.5 m, with medium wear to 28.7 m, and with strong wear to 26.1 m. The main hydraulic parameters of the pump according to the degree of impeller wear are shown in table 3.

Table 3 Main hydraulic parameters of the pump according to impeller wear

Impeller condition	**Amount of eating (mm)**	**Pressure H (m)**	**FIC (%)**
New	0.0	31.5	72
Medium level	1.0	28.7	63
Strongly corroded	2.0–2.3	26.1	56

This situation was accompanied by a general decline in energy efficiency.

The results showed that the EE decreased consistently as the impeller was corroded, namely 72% for a new impeller, 63% for moderate impeller corrosion, and 56% for severe corrosion.

As a result, the hydraulic losses were 1.8 m, 2.4 m and 3.1 m, respectively.
It was observed that this increase in hydraulic losses shifted the pump operating point to the left on the graph, leading to a decrease in the pump's EE.
The most noticeable change in impeller wear was the drop in EE. The diagram shows:

- The new impeller maintains high energy efficiency,
- When erosion reaches 1 mm, the EE drops to ~9%,
- With a wear of 2 mm, the EE drops to ~16%.

This shows that the EE decline is not linear, but rather has an accelerating character as the wear rate increases. The slope of the line in the diagram confirms that the geometric changes in the impeller lead to sharp losses in the flow.
As a result of the erosion, the pump's operating schedule underwent the following changes:

1. The $Q-H$ graph line shifted downward, but the pressure decreased;
2. The $Q-\eta$ line shifted to the left, but the optimal operating point changed;
3. P energy consumption remained unchanged, but efficiency decreased, but energy waste increased.

This process turned out to be the main factor in the decrease in energy efficiency.

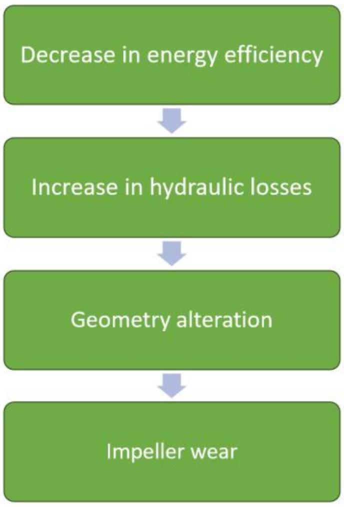

Figure 2. How impeller wear affects energy efficiency in a sequential manner

The block diagram shows how impeller wear sequentially affects energy efficiency. Wear first changes the shape of the impeller surfaces, creating irregularities and local vortices in the flow channel. This leads to an increase in hydraulic resistance, an increase in the local loss coefficient k. As losses increase, the pump's pressure capacity decreases, the EE decreases, and energy consumption increases. Thus, impeller wear gradually leads to a decrease in pump efficiency.

Discussion

The results once again confirmed that impeller wear is one of the main factors reducing the energy efficiency of the pump. The analysis showed that even at the initial stage of the wear process, local vortices are intensified due to the narrowing of the flow channel and the violation of the velocity distribution. This leads to a sharp increase in hydraulic losses, and as a result, a decrease in the head.

If the internal flow direction in a new impeller is close to ideal, then in a worn impeller the tendency of the flow to move from the center to the periphery increases, and part of the flow is wasted on useless vortex energy. Practical results have confirmed that with moderate wear alone, the EE decreases by 8–10%, and with severe wear this figure reaches 15–18%. This leads to an increase in electricity consumption even when the pump is operating in nominal mode. Also, measurements of the k coefficient showed that a 1–2 mm geometric change in the impeller surface significantly increases the hydraulic resistance. The most negative aspect of this process is that wear is not uniform - it often begins at the tips of the blades or leading edges. As a result, shear forces increase in some zones of the flow, creating favorable conditions for cavitation. Cavitation, in turn, causes even faster metal corrosion, and the process accelerates in a chain manner.

Another important aspect of the results is the change in the pump operating curve. As wear increases, the optimal operating point of the pump shifts to the left and down, and the pump efficiency decreases throughout the operating range. This is especially noticeable in stations operating at variable loads. Under such conditions, impeller wear not only increases energy consumption, but also reduces the hydraulic stability of the system.

The analysis shows that even small impeller wear, if not detected in time, significantly reduces the energy efficiency of the pump. Therefore, monitoring the condition of the impeller, reducing abrasive particles in the water, choosing the right material and optimizing the service interval will increase the efficiency of maintenance. Such an approach can not only extend the service life of the pump, but also significantly reduce the annual energy costs of the plant.

Conclusion

The results of this study confirmed that impeller wear is a major factor significantly affecting the energy efficiency and hydraulic performance of pump units. Even 1–2 mm geometric changes in the impeller surfaces narrow the effective area of the flow channel, cause local vortices to increase, and as a result, hydraulic losses increase. Measurements showed that as the wear rate increases, the pressure drop and the reduction in the EE become not linear, but rather accelerating. This shifts the optimal operating point of the pump to the left and down on the graph, reducing the overall energy efficiency of the system.

According to the analysis results, with moderate wear of the impeller, the EE decreased by about 8–10%, while with severe wear, this figure reached 15–18%. Such changes lead to increased electricity consumption, significant economic losses during long-term operation of the pump. Also, increased hydraulic losses associated with an increase in the coefficient k can cause pressure instability in water supply or production systems.

The results of the study show that if impeller wear is detected at an early stage, pump efficiency can be restored and energy waste can be prevented. Therefore, regular monitoring of the geometric changes of the impeller surface, special attention to the material when choosing a pump in the presence of abrasive particles, strengthening anti-cavitation measures and optimizing service intervals can significantly increase efficiency.

The results of this study serve as a practical basis for improving maintenance strategies at pumping stations, reducing energy consumption, and extending pump service life. In the future, real-time monitoring of the wear process through IoT sensors and the use of models predicting wear dynamics will allow for more efficient solutions in pump operation.

References

1. RB Randall, Vibration-based Condition Monitoring: Industrial, Aerospace and Automotive Applications. Chichester, UK: Wiley, 2011.
2. JS Mitchell, Machinery Vibration: Measurement and Analysis. New York, NY, USA: McGraw-Hill, 1993.
3. S. Nabavi and L. Behzad, "Bearing fault detection using vibration signals and FFT analysis," Mechanical Systems and Signal Processing, vol. 45, pp. 1–12, 2014.
4. S. Prabhakar and AR Mohanty, "Analysis of rolling bearing vibration signals using wavelet transform," Journal of Sound and Vibration, vol. 260, pp. 97–109, 2003.
5. RB Randall and J. Antony, "Rolling element bearing diagnostics—A tutorial," Mechanical Systems and Signal Processing, vol. 25, pp. 485–520, 2011.
6. M. Elforjani and D. Mba, "Condition monitoring of slow-speed shafts using acoustic emission and vibration analysis," NDT & E International, vol. 42, pp. 189–198, 2009.
7. Y. Lei, Z. He, and Y. Zi, "A new approach to fault diagnosis of rotating machinery based on ant colony optimization and wavelet transform," Mechanical Systems and Signal Processing, vol. 21, pp. 355–370, 2007.
8. SP Harsha, "Nonlinear dynamic response of a misaligned rotor system," Mechanism and Machine Theory, vol. 49, pp. 1–11, 2012.
9. SD Pathak and SS Handa, "IoT-based fault detection of rotary machines using vibration sensors," IEEE Sensors Journal, vol. 20, no. 18, pp. 10865–10872, 2020.