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Performance Analysis of Centrifugal Pumps Before and After Wear Ring Restoration

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Abstract

A pump is a mechanical device used to move fluids from a lower elevation to a higher one. In general, pumps are classified into two types: positive displacement pumps and non-positive displacement pumps. Centrifugal pumps fall into the latter category and operate by converting mechanical energy into kinetic energy to transport fluids. A centrifugal pump consists of several key components, including the casing, shaft, bearing, coupling, and impeller. In the case of closed impeller-type centrifugal pumps, wear rings (wearing components) are installed to provide a clearance between the impeller and the casing, preventing physical contact during operation. The size of this clearance significantly affects pump performance. Wear ring damage can result from mechanical wear, corrosion, cavitation, and fatigue, leading to performance losses such as reduced flow rate, lower pressure, and decreased efficiency. This research aims to analyze the effect of wear ring damage on the performance of a centrifugal pump by comparing operational data before and after repair of the wearing components. The performance parameters evaluated include pump head, pressure, hydraulic power, motor power, and overall efficiency. Data were collected through a structured procedure consisting of preparation, testing, measurement, and analysis. Prior to repair, the pump operated with a wear ring clearance of 1.2 mm, resulting in an average efficiency of 8.5% and a flow rate of 0.000646 m^3/s. After the clearance was restored to 0.43 mm, the average efficiency increased to 15.5%, with a corresponding flow rate of 0.000932 m^3/s. These results demonstrate that maintaining wear ring clearance within recommended standards significantly improves pump performance, highlighting the importance of regular maintenance and timely component repair.

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1. Introduction

Industrial development in Indonesia has experienced rapid growth, driven by technological advancements and the establishment of large-scale enterprises across diverse sectors such as agriculture, education, textiles, food, mining, and petrochemicals. Among these, the petrochemical industry plays a vital role by producing a range of organic chemical products derived from the processing of oil and gas, coal, and biomass-based oleochemicals [1]. To support the production process, petrochemical plants rely on various critical mechanical systems, including pumps, compressors, heat exchangers, furnaces, vessels, distillation columns, condensers, coolers, separators, valves, piping systems, and instrumentation [2]. Pumps, in particular, serve as essential mechanical devices driven by electric motors or engines to transfer fluids from one location to another, with the goal of increasing pressure, flow rate, or fluid velocity [3].

One commonly used type is the centrifugal pump, which relies heavily on the performance of its key component, the impeller. The impeller functions to increase the fluid's head and capacity, directly influencing the pump's overall efficiency [4]. Impellers are typically classified into three types: closed, open, and semi-open [5]. In closed-type impellers, a critical component known as the wear ring (or *wearing*) is installed, usually on the stationary side of the pump casing [6]. This component plays a crucial role in minimizing internal leakage by reducing the clearance between the impeller and the casing. An increase in this clearance can lead to higher leakage rates, reduced flow rate, and a decline in pump performance [7].

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Wear rings are susceptible to damage from multiple factors such as mechanical wear, cavitation, corrosion, and fatigue [8]. Changes in pressure and flow rate across valves can also influence pump performance. For instance, smaller valve openings may result in higher head values but correspondingly lower flow rates [9]. The clearance between the impeller and volute must be tightly controlled, as excessive clearance not only allows more leakage but also reduces both volumetric and hydraulic efficiency [10]. Furthermore, the relationship between discharge and shaft power is directly proportional—greater discharge requires increased shaft power [11].

Given the importance of wear rings in maintaining centrifugal pump performance, this study investigates the efficiency of centrifugal pumps before and after wear ring repair. The focus is on analyzing how wear or damage—especially from solid-liquid interactions—can degrade pump efficiency over time. Particles such as sediment, when suspended in the pumped fluid, often cause abrasive wear to vital pump components like the impeller and volute.

Serrano et al. emphasized that particle size and concentration significantly affect wear severity, noting how sediment-induced erosion deforms impeller blades and diminishes pump efficiency [12]. Similarly, Li et al. demonstrated that maximum wear typically occurs on critical surfaces such as impeller vanes and rear covers due to impact erosion by solid particles [13].

Wang et al. further explored wear behavior using advanced modeling techniques, revealing that wear characteristics are influenced by changes in flow rate, particle size, and volume concentration [14]. Their findings underscore the need for predictive maintenance strategies, especially in operations involving high volumes of abrasive particles, as also supported by studies from Yan et al. and Jiang et al. [15], [16].

The effect of wear-ring clearance on pump performance has also been well documented. Wu et al. found that increased wear-ring clearance could result in a head reduction of approximately 3.56% and an efficiency loss of 9.62% [17]. Daqiqshirazi et al. corroborated these findings, showing that prolonged exposure to abrasive conditions accelerates internal leakage and decreases efficiency [18].

Wear and erosion in centrifugal pumps—particularly around the impeller and wear ring—are critical factors affecting long-term performance and reliability. Through comparative analysis, this study aims to provide insights into how restoring worn components can recover pump efficiency and inform better maintenance strategies in abrasive environments.

2. Methods

The research methodology is outlined in the flowchart presented in Figure 1, which illustrates the sequential steps taken to evaluate the effect of wear ring clearance on centrifugal pump performance. The study began with the selection of the research object and a comprehensive literature review to gather theoretical and technical references relevant to centrifugal pump systems. Following this, preparatory work was conducted for the repair and replacement of the impeller and associated wear ring components.

Once the pump was restored, performance testing was carried out under operational conditions. Data collection focused on key performance indicators, including head, brake horsepower (BHP), and efficiency. These parameters were recorded for different clearance variations to analyze their impact on pump operation. The collected data was then processed using theoretical formulas commonly applied in centrifugal pump performance analysis. If the results were deemed unsuitable, the process looped back for re-testing and further refinement.

The centrifugal pump used in this study is manufactured by Ebara Corporation and has the following specifications: a motor power of 5.5 kW, shaft power of 3.59 kW, current of 9 A, voltage of 380 V, and cos ϕ value of 0.90. It operates at a speed of 2920 rpm, with a capacity of 3.5 m^3/h and a head of 50 m. The pump employs a closed impeller design and demonstrates baseline efficiency of 16.5%, as shown in Table 1. The aim of the analysis is to determine the optimal wear ring clearance that minimizes efficiency losses and enhances overall pump performance.

Several key instruments and tools were used to monitor and evaluate pump performance. Pressure gauges with a range of 0–10 bar and an accuracy of ±0.5% were installed on both the suction and discharge sides of the pump. A digital flow meter, accurate to within ±1%, was used to measure discharge flow rate. A clamp meter was employed to monitor electrical current, and a laser tachometer was used to confirm the motor shaft's rotational speed. A digital wattmeter was connected to assess power input to the motor. Wear ring clearance was measured using calipers and feeler gauges. A data acquisition system (DAQ) was employed to log real-time data from the experiments.

Prior to experimentation, all instruments were calibrated using reference standards to ensure accuracy. Pressure and flow meters were verified using a standard hydraulic bench. The tachometer was validated against a reference motor with a known RPM. Calibration ensured the reliability of the collected data and minimized errors during analysis.

The experiment began with the installation of the pump onto a fixed test bench connected to a closed-loop water circulation system. Initial measurements were taken under baseline conditions, i.e., with the original wear ring clearance. The pump was operated for 10–15 minutes to reach a steady-state condition before measurements were recorded. Performance indicators such as head, flow rate, shaft power, and efficiency were documented. After the baseline testing, the pump casing was opened, and the wear ring was either replaced or reconditioned to achieve standard clearance. The wear ring gap was measured using feeler gauges to ensure accuracy. The pump was then reassembled and subjected to another round of performance testing under the same operational conditions.

2.1. American Petroleum Institute 610 standard

API 610 is the standard for centrifugal pumps used in the oil and gas industry. This standard specifies design, material, manufacturing, inspection and testing requirements to ensure pump safety, reliability and availability. Some of the important features include casing design, shaft, impeller, shaft deflection, bearing design life, vibration.

Table 1. API 610 Standard for minimum diametral clearance

Diameter of rotating member at clearance (mm)	Minimum diametral clearance (mm)			
	Manufacturer's Std (0.75 x API 610)	Nonmetallic	API 610	API 610 'Hot'
< 50	0.188	0.125	0.25	0.375
50 to 64.99	0.21	0.14	0.28	0.405
65 to 79.99	0.225	0.15	0.3	0.425
80 to 89.99	0.248	0.165	0.33	0.455
90 to 99.99	0.263	0.175	0.35	0.475
100 to 114.99	0.285	0.19	0.38	0.505
115 to 124.99	0.308	0.205	0.41	0.535
125 to 149.99	0.323	0.215	0.43	0.555
150 to 174.99	0.338	0.225	0.45	0.575
175 to 199.99	0.36	0.24	0.48	0.605
200 to 224.99	0.375	0.25	0.5	0.625
225 to 249.99	0.398	0.265	0.53	0.655
250 to 274.99	0.413	0.275	0.55	0.675
275 to 299.99	0.435	0.29	0.58	0.705

In this study, the selection of wear ring clearances was based on a combination of API 610 guidelines, manufacturer recommendations, field observations, and insights from the technical literature on centrifugal pump performance and maintenance. A wear ring clearance of 0.43 mm was selected as the benchmark for optimal performance, aligning with the API 610 standard for pumps with impeller diameters between 125 mm and 149.99 mm. This value is widely accepted in industrial practice for maintaining efficiency while minimizing the risk of contact between the impeller and casing.

Conversely, a clearance of 1.2 mm was selected to simulate a severely worn condition, which is representative of pumps that have been subjected to prolonged operation without scheduled maintenance. According to field maintenance records from petrochemical facilities, wear ring clearances exceeding 1.0 mm are frequently linked to significant efficiency losses, increased internal recirculation, and greater vibration levels. Therefore, the choice of 0.43 mm and 1.2 mm as test cases provides a clear and measurable contrast, enabling a thorough evaluation of pump performance degradation due to excessive wear.

2.2. Pump reability analysis

Performance calculations were conducted using standard centrifugal pump equations, including total head, water horsepower (WHP), brake horsepower (BHP), and pump efficiency. Additionally, failure mode and effect analysis (FMEA) were carried out to evaluate the severity, occurrence, and detection of potential failures

In determining the performance of a pump system, the primer parameter is to know the discharge and head needed to drain the liquid to be pumped. The pump head that must be provided to drain the planned water discharge can be determined from the installation conditions to be used by the pump, the total heat of the pump can be calculated by the equation [19]:

$$H = \frac{\Delta P}{\rho g} \tag{1}$$

Where:
H = Total pump head (m)
ΔP = Pressure difference (discharge pressure – suction pressure) (Pa)
ρ = Fluid density (kg/m^3)
g = Acceleration due to gravity (9.81 m/s^2)

Water Horse Power (WHP) refers to the hydraulic power produced by a centrifugal pump to deliver a specific discharge at a given head. WHP can be calculated using the following expression [20]:

$$WHP = {}^{\gamma\ H\ Q}\!/_{1000} \tag{2}$$

Where:
WHP = Water horse power (kW)
γ = Specific weight of water (N/m^3)
Q = Flow discharge (m^3/s)
H = Total pump head (m)

Brake Horse Power (BHP) is the actual shaft power needed to drive the pump, supplied by the motor or engine. BHP accounts for pump efficiency and is calculated as follows:

$$BHP = {}^{WHP}\!/_{\eta_{pump}} \tag{3}$$

Where:
BHP = Brake Horse Power (kW)
WHP = Water Horse Power (kW)
η_{pump} = Pump efficiency

Failure Mode and Effect Analysis (FMEA) is a systematic technique used to identify and analyze potential failure modes, their causes, and consequences in order to prioritize corrective actions. Three key aspects are considered in FMEA: Occurrence (O), Severity (S), and Detection (D). These factors are used to calculate the Risk Priority Number (RPN) using the formula [21], [22]:

$$RPN = occurence \times severity \times detection \tag{4}$$

The RPN value serves as a metric for comparing potential risks and prioritizing mitigation strategies.

To assess the reliability of a centrifugal pump, two fundamental parameters must be determined: the Mean Time Between Failures (MTBF) and the failure rate (λ). MTBF indicates the average operational time before a failure occurs and is calculated as [23]:

$$MTBF = Operating\ Time/No. of\ Failure \tag{5}$$

The failure rate (λ) is the inverse of MTBF:

$$\lambda = {}^{1}\!/_{MTBF} \tag{6}$$

Using the failure rate, the reliability function R(t), which defines the probability that the pump will perform without failure over a given time period t, is expressed as:

$$R(t) = e^{-\lambda t} \tag{7}$$

where:
R = Reliability at time t
e = Euler's number (approximately 2.718)
λ = Failure rate (1/hour)
t = Operating time (hours)

3. Results and Discussion

3.1. Centrifugal pump performance before wearing repairs

Observations and data collection were conducted at three-hour intervals over a two-day period, from October 11 to 12, 2023. During this period, the performance of the centrifugal pump was monitored in its worn condition, prior to any repair or component replacement. Key parameters measured included head, brake horsepower (BHP), water horsepower (WHP), and pump efficiency (η). The recorded data are presented in Table 2.

Table 2. Pump performance data before repair

Time (WIB)	Head (m)	BHP (W)	WHP (W)	η
09.00	40.91	3427	302	0.09
12.00	41.79	3165	327	0.10
15.00	41.79	3251	314	0.10
18.00	40.02	3517	326	0.09
21.00	40.46	3427	316	0.09
00.00	40.20	3480	277	0.08
03.00	39.93	3427	288	0.08
06.00	39.66	3517	261	0.07
09.00	39.40	3427	246	0.07

`

The data above indicate that the pump experienced a consistent decrease in efficiency throughout the observation period. The average pump efficiency was calculated at 8.5%, which is significantly below the expected performance range for centrifugal pumps operating under optimal conditions. This confirmed that the internal wear, particularly at the wear ring and impeller, was adversely affecting the hydraulic performance of the pump.

3.2. Inspection and repair results based on the type of pump damage

Following the performance evaluation, a detailed inspection of the pump was conducted to identify the root causes of inefficiency. The inspection included run-out measurements, wear ring clearance verification, shaft straightness checks, and visual inspection of bearings and housings. Table 3 summarizes the findings and the corrective actions taken.

Table 3. Pump component inspection and repair summary

Component	Inspection Result	Repair Action
Wear ring	Clearance out of tolerance (1.2 mm)	Re-machined to 0.43 mm using lathe (API 610 standard)
Shaft run-out	Shaft bent on impeller side (0.8 mm deviation)	Shaft straightened and re-machined
Bearing housing	Within acceptable tolerance (+0.01 to +0.02 mm)	No action required
Bearings	No visible damage was found during inspection	Replaced to avoid hidden defect risk during reassembly
Alignment	Misalignment: 0.23 mm (horizontal), 0.20 mm (axial)	Realigned using dial gauge; final values within 0.05 mm

The inspection revealed an excessive wear ring clearance of 1.2 mm, well above the API 610 standard limit of 0.43 mm, which significantly contributed to internal leakage and energy loss. Additionally, the pump shaft was found to be bent, and minor misalignment was observed, both of which were corrected. Although the bearing housing was within tolerance, the bearings were replaced as a preventive measure.

3.3. Pump performance after repair

Following the repairs, including wear ring clearance restoration and shaft reconditioning, the pump was reassembled and re-tested under the same operating conditions. Data collection was conducted over two consecutive days, from October 13 to 14, 2023, using the same observation intervals. Table 4 presents the performance data after repair.

Table 4. Pump performance data after repair

Time (WIB)	Head (m)	BHP (W)	WHP (W)	η
09.00	50.58	3517	536	0.15
12.00	50.58	3427	524	0.15
15.00	50.13	3462	531	0.15
18.00	50.58	3427	524	0.15
21.00	50.13	3517	548	0.16
00.00	50.58	3480	542	0.16
03.00	51.02	3427	529	0.15
06.00	50.13	3517	548	0.16
09.00	51.02	3427	529	0.15

After repairs, the pump showed significant improvement across all performance parameters. The average head increased from approximately 40.4 meters to 50.4 meters, and the pump efficiency nearly doubled, rising from 8.5% to 15.5%. This clearly indicates the effectiveness of restoring wear ring clearance and correcting shaft alignment. The improved hydraulic performance suggests that internal leakage was significantly reduced, and energy transfer was more efficient. Various studies have demonstrated that factors such as impeller diameter and blade design directly affect operational stability and performance characteristics, highlighting the need for precise engineering during repairs [24], [25].

3.4. Correlation of wear ring clearance with centrifugal pump head

Monitoring and performance calculations of the centrifugal pump before and after repairs were conducted using the equation:

$$H = {P_{discharge} - P_{suction}}/{\rho\, g} \tag{8}$$

This allowed for the determination of the pump head based on real-time pressure measurements and fluid properties. The resulting data were plotted to evaluate the influence of wear ring clearance on pump head performance, as shown in Figure 1.

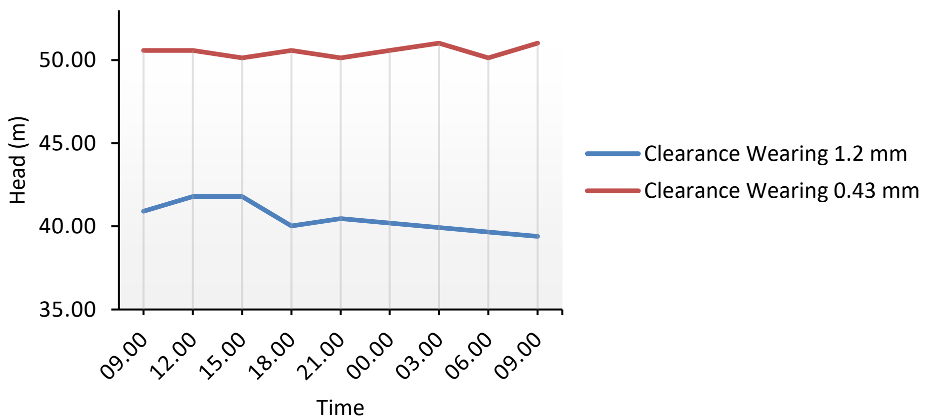

Figure 1. Correlation of wear ring clearance to pump head

The graph in Figure 1 illustrates that wear ring clearance has a direct and significant impact on pump head. With a worn clearance of 1.2 mm, the average pump head was measured at 40.45 meters. In contrast, after the wear ring was repaired to the API 610 standard clearance of 0.43 mm, the average pump head increased to 50.52 meters. This finding demonstrates that smaller wear ring clearances result in higher pump head, due to reduced internal leakage and improved hydraulic efficiency.

3.5. Correlation of wear ring clearance with pump efficiency

The efficiency of the centrifugal pump was calculated using the formula:

$$\eta = \left({}^{WHP}/_{BHP}\right) \times 100\% \tag{9}$$

Efficiency measurements were collected both before and after the repair of the wearing impeller. The correlation is presented in Figure 2. As shown in Figure 2, a clear relationship exists between wear ring clearance and pump efficiency. When operating with a 1.2 mm clearance, the average efficiency was 8.5%. After restoring the clearance to 0.43 mm, the average efficiency nearly doubled to 15.5%. The improvement highlights the importance of maintaining proper clearance within specified tolerances to reduce internal fluid recirculation and energy loss.

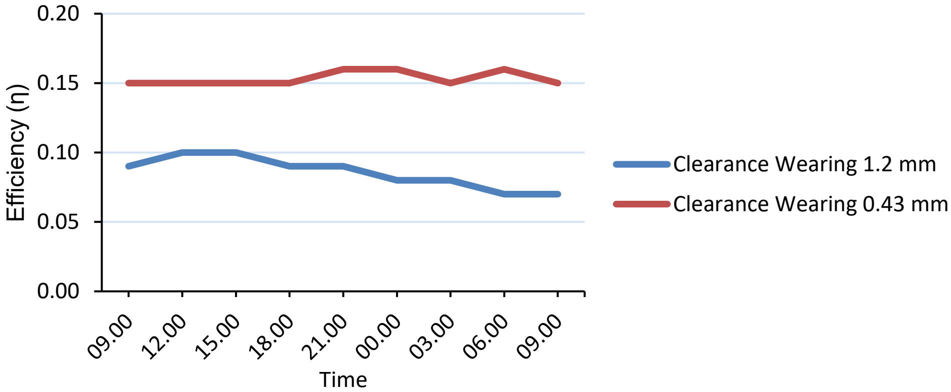

Figure 2. Correlation of of wear ring clearance to pump efficiency

3.6. Impeller reliability assesment

To assess the reliability of the impeller, historical data and failure analysis were used as the basis for a Failure Mode and Effect Analysis (FMEA). This approach helped identify potential failure mechanisms and their associated risks. The FMEA results are summarized in Table 5.

Table 5. FMEA for centrifugal pump impeller

Functional failures	Effects of Failure	RPN
Wear ring worn out	Decreased pump efficiency	210
Clogging caused by dirt	Unstable pressure and discharge	96
Impeller erosion	Pump inoperable	96
Inner diameter worn out	Excessive vibration	108

Table 6. Failure rates of impeller components

Functional failures	(λ)
Wearing has worn out	0.000228
Clogging caused by dirt	0.000285
Erosion impeller	0.000114
Inside diameter worn out	0.000057

Among the failure modes, wear ring wear had the highest Risk Priority Number (RPN) of 210, confirming it as the most critical issue affecting efficiency and reliability. The impeller's reliability was further analyzed using failure rate data and assumed operational durations. Table 6 outlines the failure rates for each failure mode, while Table 7 presents the resulting reliability values based on cumulative operating hours.

Table 7. Reliability of the impeller over time

Operating Hours	Reliability
500	91.8%
1000	84.28%
1500	76.8%
2000	69.24%
2500	61.7%
3000	54.20%

The data show a clear decline in impeller reliability as operating hours increase. After 1500 hours, the reliability dropped to 76.8% and further decreased to 54.2% after 3000 hours. According to the Indonesian Industrial Standard (SII), the minimum acceptable reliability threshold for operational machinery is 70%. Thus, this study confirms that scheduled maintenance or component replacement is necessary before reaching 2000 hours of continuous operation to maintain system reliability.

4. Conclusions

Based on the results of this study, wear ring clearance has a significant impact on the hydraulic performance and reliability of centrifugal pumps. Two clearance variations were evaluated: 0.43 mm (standard clearance) and 1.2 mm (worn clearance). The average efficiency achieved with a 0.43 mm clearance was 15.5%, while with a 1.2 mm clearance, efficiency dropped to 8.5%. Similarly, the average flow discharge recorded was 3.45 m^3/h for the 0.43 mm clearance and only 2.33 m^3/h for the 1.2 mm clearance. In terms of pump head, the 0.43 mm clearance yielded an average of 50.52 meters, whereas the 1.2 mm clearance resulted in a reduced head of 40.45 meters. These findings confirm that smaller wear ring clearances significantly improve pump head, discharge, and overall efficiency by minimizing internal leakage and hydraulic losses. Furthermore, the impeller reliability analysis showed that continuous operation beyond 2000 hours without corrective maintenance leads to a sharp decline in reliability, falling below the acceptable 70% threshold as set by the Indonesian Industrial Standard (SII). To maintain optimal performance and ensure equipment reliability, it is recommended that preventive maintenance be scheduled regularly, with specific attention to monitoring wear ring clearance, shaft alignment, and impeller condition. Implementing these measures can extend the service life of the pump, reduce operational costs, and improve system availability in industrial applications.

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