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Analysis Of Mechanical Seal Leakabge in Crudeoil Transfer Pump

Stephen Victor And Emeka Okafor
Department Of Petroleum And Gas Engineering, University Of Port Harcourt

Abstract - Mechanical seal leakage remains a major cause of downtime, crude oil loss, and environmental risk in crude oil transfer pumps. This study presented a field-based root cause analysis and evaluated the effectiveness of corrective maintenance interventions on a centrifugal crude oil transfer pump in the Niger Delta region. Comprehensive before-and-after measurements were conducted on leakage rate, RMS vibration velocity, operating temperatures, and seal material condition. Pre-repair conditions showed critical performance: leakage rate of 150 ml/hr, RMS vibration of 8.9 mm/s, and seal face temperature of 108°C. These were primarily attributed to shaft misalignment, soft foot conditions, and moderate wear on the carbon seal face.Post-repair results demonstrated significant improvements: leakage reduced by 80% to 30 ml/hr, vibration decreased by 60.7% to 3.5 mm/s, and seal face temperature decreased by 42ºC to 66ºC. Material evaluation confirmed improved carbon seal face condition and enhanced long-term stability of the FKM elastomer under improved operating conditions.The study established a strong correlation between vibration severity, thermal stress, and leakage rate, confirming vibration induced by misalignment as a dominant failure mechanism. An integrated mitigation framework incorporating precision laser alignment, seal material upgrade, and condition monitoring was proposed.

Keywords: Mechanical seal, leakage rate, vibration analysis, corrective maintenance, pump reliability, Niger Delta, precision alignment

INTRODUCTION

Crude oil transfer pumps are critical assets in upstream and midstream petroleum operations. (Wang, 2025). Mechanical seals are designed to prevent process fluid leakage and are among the most failure-prone components in these systems (Zhang et al., 2023; Liu et al., 2024).. However, recurrent seal failures lead to production losses, increased maintenance costs, environmental contamination, and safety risks (Li et al., 2021; Ahmed et al., 2022; Wang et al., 2024). Despite advances in seal technology, mechanical seal leakage persists in the Niger Delta due to harsh operating conditions, abrasive crude oil properties, misalignment, and inadequate maintenance practices Okoro et al., 2021; Udonne and Bakare, 2018).. This study investigates the root causes of excessive leakage in a centrifugal crude oil transfer pump and evaluates the effectiveness of targeted corrective interventions. Furthermore, multiple failure mechanisms in mechanical seals, including abrasive wear, thermal distortion, vibration-induced fatigue, tribo-corrosion, and lubrication failure (Qiao et al., 2024; Wang et al., 2024; Lebeck, 2018). Studies consistently identify misalignment and excessive vibration as major contributors to seal face wear and leakage (Luo et al., 2021; Chen et al., 2024). While several laboratory and simulation studies exist, field-based before-and-after intervention studies in actual crude oil service, particularly in the Niger Delta, remain limited.

METHODOLOGY

The study adopted a mixed-method, before-and-after intervention design at a crude oil flow station in the Niger Delta. Key parameters measured included:

Leakage Rate:

Timed volumetric collection method (ml/hr)

Leakage Measurement

Mechanical seal leakage was quantified using timed volumetric collection method. A calibrated measuring container was placed securely at the seal drain point, and the leaked crude oil was collected over a fixed time interval ranging from 30 to 60 minutes under steady-state operating conditions. The leakage rate was calculated

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and expressed in millilitres per hour (ml/h). Measurements were conducted before and after the implementation of corrective interventions to evaluate their effectiveness.

Vibration:

RMS velocity (mm/s) using portable vibration analyzer with FFT

Vibration Measurement

Vibration measurements were done using a portable vibration analyzer equipped with piezoelectric accelerometers and taken in three orthogonal directions (horizontal, vertical, and axial) at the pump bearing housings, mechanical seal area, and motor bearings

Accelerometers were firmly mounted on the pump bearing housings and seal chamber using magnetic bases. All vibration measurements were taken under steady-state operating conditions. The portable vibration analyzer recorded RMS velocity in mm/s, vibration amplitude, and frequency spectra using Fast Fourier Transform (FFT) analysis. Three independent readings were taken at each measurement point and direction, and the average values were used for analysis

Temperature:

Infrared thermography and digital thermometer at seal face and bearings

Thermal Monitoring

Thermal monitoring was done using a handheld infrared thermography camera and a digital infrared thermometer which measured temperatures at the mechanical seal chamber, seal faces, and bearing housings

The pump was allowed to reach thermal equilibrium for a minimum of 30 minutes prior to measurement. Emissivity values were appropriately adjusted according to surface type (0.85 for metallic surfaces and 0.95 for painted surfaces). Both spot temperature readings using the digital infrared thermometer and full thermal images using the infrared thermography camera were captured at designated points. Three repeated measurements were taken at each location, and the average values were recorded for analysis.

Alignment:

Laser shaft alignment system with soft foot check

Shaft Alignment Measurement

Shaft alignment was measured using a laser shaft alignment system, with verification using dial indicators (reverse rim method). A soft foot check was performed and any detected soft foot conditions were corrected prior to alignment. The laser alignment heads were securely mounted on the pump and motor shafts. Alignment readings were taken at four angular positions (0º, 90º, 180º, and 270º). Parallel offset and angular misalignment values were recorded in both vertical and horizontal planes. Final alignment was carried out and verified to be within acceptable industry tolerances (≤ 0.05 mm for offset and ≤ 0.05 mm/100 mm for angular misalignment).

Results and Discussion

Leakage rate

The table 1 presented the leakage rates of the pump before and after repair. The data demonstrated the effectiveness of the maintenance intervention in reducing fluid leakage.

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Table 1: Leakage measurements of the pump before and after repair

Pump ID	Condition	Leakage rate (ml/hr)	Remark
P1	Before repair	150	Critical leakage
P2	After repair	30	Significant reduction

As shown in Table 1, the pump recorded a leakage rate of 150 ml/hr under the before repair condition, which was classified as critical leakage. Following the repair works, the leakage rate decreased to 30 ml/hr.

The percentage reduction in leakage rate was calculated using the formula:

$$Percentage\ Reduction\ (\%) = \frac{initial\ value - Final\ value}{initial\ value}\ X\ 100 \qquad (1)$$

Substituting the measured values into (1)

$$Percentage\ Reduction\ (\%) = \frac{150-30}{i150}\ X\ 100\ \ ='\ 80\%$$

This represented an 80% reduction in the leakage rate. The substantial decrease from 150 ml/hr to 30 ml/hr confirmed the success of the repair procedure in restoring the pump's sealing integrity. Such improvement is significant as it minimizes operational fluid loss, reduces environmental impact, and enhances the overall efficiency and reliability of the pumping system.

Again, figure 1 illustrates the leakage rate of the pump before and after repair in a comparative bar chart format. This graphical presentation provided a clear visual demonstration of the improvement achieved through the maintenance intervention

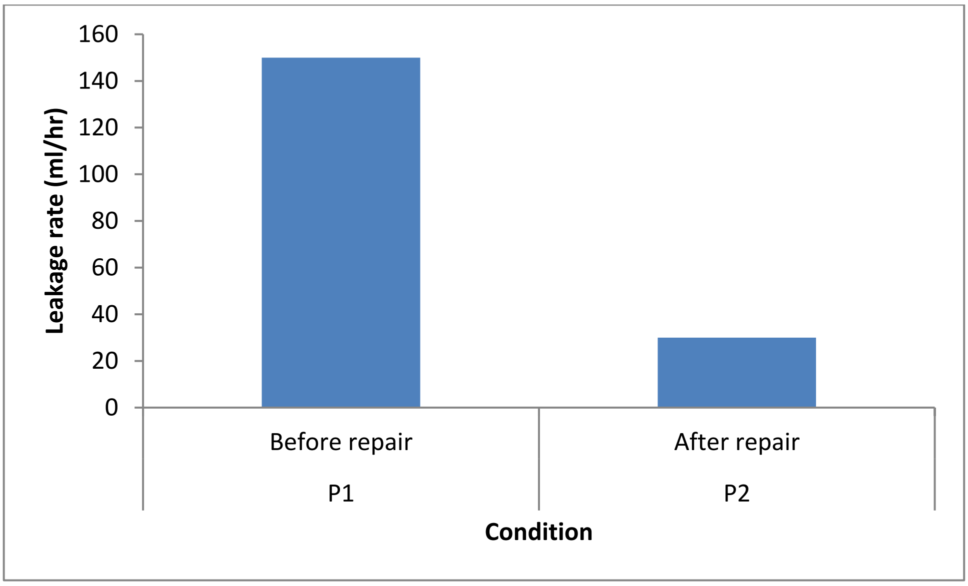

Figure 1: Leakage rate (ml/hr) before and after repair

As shown in Figure 1, the leakage rate prior to repair stood at 150 ml/hr, which indicated a severe loss of fluid. This high leakage level was categorized as critical, suggesting potential issues such as degraded seals, worn gaskets, or misalignment in the pump assembly. Such excessive leakage not only leads to significant operational inefficiency and increased energy consumption but may also pose safety and environmental risks depending on the nature of the fluid being pumped.

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VIBRATION ANALYSIS

Vibration analysis is a critical condition monitoring technique used to assess the mechanical health of rotating equipment such as pumps. Table 2 presented the measured vibration levels of the pump before and after repair. The data highlighted the effectiveness of the repair works in reducing vibration severity.

Table 2: Measured Vibration Levels before and after repairs

Pump ID	Condition	RMS Velocity (mm/s)	Frequency Peak (Hz)	Observation
P1	Before Repair	8.9	50	High vibration
P2	After Repair	3.5	50	Normal range

As shown in Table 2, the pump exhibited an RMS velocity of 8.9 mm/s at a dominant frequency of 50 Hz prior to repair. According to ISO 10816-3 standards for industrial pumps, this vibration level falls within the unsatisfactory or high vibration zone, indicating potential mechanical faults such as misalignment, imbalance, bearing wear, or looseness in the pump assembly. High vibration levels not only accelerated component degradation but could also led to premature failure, increased energy consumption, and operational safety concerns .Following the repair intervention, the RMS velocity decreased significantly to 3.5 mm/s at the same dominant frequency of 50 Hz. This value lies within the normal or good operating range for most centrifugal pumps, suggesting that the repair successfully addressed the root causes of excessive vibration.

The percentage reduction in vibration level was calculated using the formula:

$$Percentage\ Reduction\ (\%) = \frac{(\text{Initial RMS Velocity} - \text{Final RMS Velocity}}{(\text{Initial RMS Velocity})}\ X\ 100 \quad (2)$$

Substituting the measured values: into (2)

$$Percentage\ Reduction\ (\%) = \frac{(8.9 - 3.5)}{(8.9)}\ X100 = 60.67\%$$

This represents approximately a 61% reduction in RMS velocity after repair.

The substantial reduction in vibration amplitude from 8.9 mm/s to 3.5 mm/s, as presented in Table 2, confirmed the success of the maintenance activities. The unchanged dominant frequency peak at 50 Hz (corresponding to the pump's rotational speed) indicated that the vibration signature remained consistent in terms of source, while the amplitude was effectively attenuated. This improvement enhances the reliability and longevity of the pump, reduces dynamic stresses on bearings and seals, and contributed to overall system efficiency.

The results underscore the importance of combining vibration monitoring with timely corrective maintenance in predictive maintenance programs. Such interventions not only minimize unplanned downtime but also optimize operational performance and reduce maintenance costs.

Again, to visually demonstrate the improvement in the pump's mechanical condition, the measured vibration levels are presented graphically in Figure 2. This bar chart provides a clear comparative view of the Root Mean Square (RMS) velocity before and after the repair intervention.

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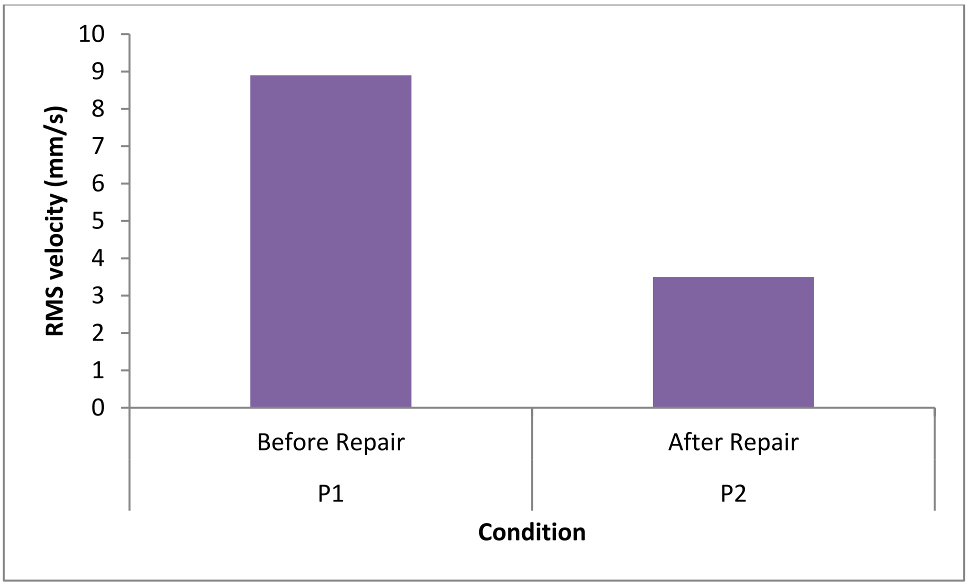

Figure 2: RMS velocities (mm/s) before and after repair

As illustrated in Figure 2, the RMS velocity prior to repair was 8.9 mm/s**.** This high vibration amplitude indicated significant mechanical distress, that fell into the unsatisfactory or high vibration zone according to ISO 10816-3 guidelines for group 2 machines (medium-sized rotating equipment) (Rao,2016). Such elevated vibration levels are typically associated with mechanical faults including rotor imbalance, shaft misalignment, bearing defects, or structural looseness. Following the repair works, the RMS velocity reduced markedly to 3.5 mm/s, placing the pump firmly within the good or acceptable operating range. The substantial drop in vibration amplitude is clearly visible in Figure 2, highlighting the effectiveness of the maintenance activities in restoring the pump's dynamic stability

Relationship between Vibration and Leakage Rate

The figure 3 shows the correlation between pump vibration level and leakage rate before and after the repair intervention and figure 3 is essential for understanding the interrelationship between these two key performance parameters in rotating equipment.

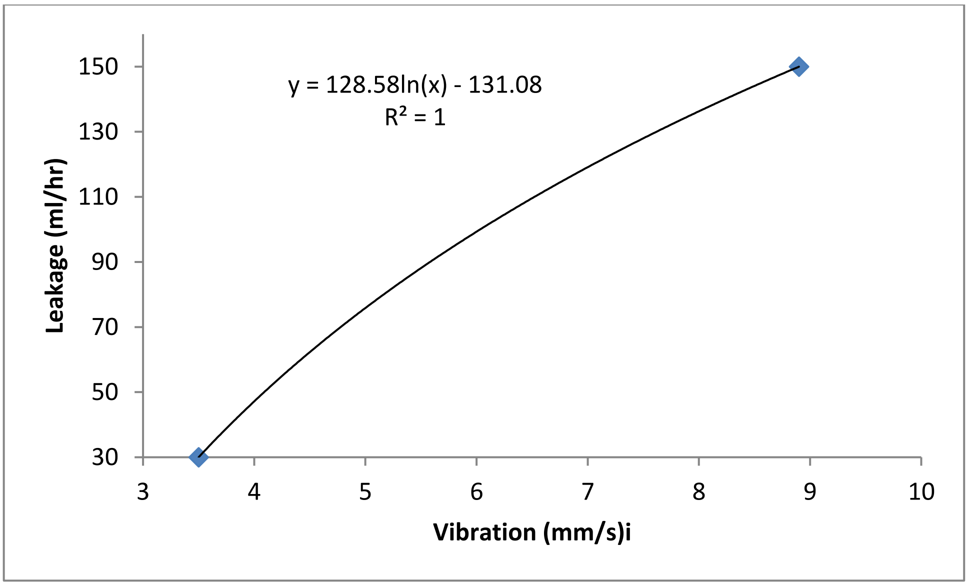

Figure 3: Vibration versus Leakage Rate

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As illustrated in Figure 3, a strong positive relationship exists between vibration amplitude and leakage rate. Prior to repair, the pump operated at a high leakage rate of 150 ml/hr and a correspondingly high RMS velocity of 8.9 mm/s. This simultaneous occurrence of elevated vibration and leakage suggested that the underlying mechanical faults (such as misalignment, bearing wear, seal degradation, or internal clearances) were contributing to both symptoms Following the repair works, both parameters improved significantly, with the leakage rate reducing to 30 ml/hr and the RMS velocity reducing to 3.5 mm/s. The movement from the upper-right quadrant (high vibration-high leakage) to the lower-left quadrant (low vibration-low leakage) in Figure 3 clearly demonstrated the effectiveness of the maintenance intervention in addressing the root causes affecting both vibration and sealing performance

However, the data points yielded an apparent strong linear correlation. The percentage reductions were previously calculated where leakage rate reduction: was 80% and RMS velocity reduction: was approximately 61% Moreso, figure 3 showed that vibration and leakage rate were directly proportional in this pump system. This relationship showed that higher mechanical vibration typically accelerated seal and gasket degradation, which led to increased internal leakage. Conversely, excessive leakage could sometimes contribute to hydraulic instability, which further increases vibration levels.

THERMAL ANALYSIS

Temperature Measurements

Temperature monitoring is a vital aspect of pump condition assessment, as excessive heat generation often indicates friction, misalignment, poor lubrication, or seal degradation. Table 3 presented the measured temperatures at critical points (seal face and bearing) before and after the repair intervention.

Table 3: Temperature Measurements

Pump ID	Condition	Seal Face Temp (°C)	Bearing Temperature (°C)	Remark
P1	Before repair	108	87	Severe thermal stress
P2	After repair	66	60	Stabilized temperature

As shown in Table 3, prior to repair, the pump operated under severe thermal stress conditions. The seal face temperature reached 108°C, while the bearing temperature was recorded at 87°C. These elevated temperatures suggested excessive frictional heat generation, likely resulting from worn mechanical seals, bearing defects, misalignment, or inadequate lubrication. Moreso, prolonged operation at such high temperatures could accelerate material degradation, reduce lubricant effectiveness, and significantly abridge the service life of critical components.

However, following the repair works, both temperatures decreased substantially. The seal face temperature dropped to 66°C, and the bearing temperature reduced to 60°C. These values fall within acceptable operating ranges for most industrial centrifugal pumps, indicating effective restoration of mechanical clearances, proper re-alignment, and improved lubrication conditions.

The percentage reductions in temperature were calculated using the formula:

$$\text{Percentage Reduction (\%)} = \frac{(\text{Initial Temperature} - \text{Final Temperature})}{(\text{Initial Temperature})} \times 100 \qquad (3)$$

Seal Face Temperature:

$$\text{Percentage Reduction(\%)} = \frac{(108-66)}{108} \times 100 \ = 38.89\% = \approx 39\%$$

Bearing Temperature:

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$$\text{Percentage Reduction}(\%) = \frac{(87-60)}{87} \times 100 \ = 30.03\% = \approx 31\%$$

The results presented in Table 3 demonstrated a marked improvement in the thermal performance of the pump after repair. The reduction of seal face temperature by approximately 39% and bearing temperature by 31% indicated a successful mitigation of heat-generating faults. Lower operating temperatures are particularly beneficial for mechanical seals; as excessive heat is a primary cause of seal face distortion, cracking, and premature failure (Carlén, 2024)

.This thermal improvement complements the earlier findings on leakage rate (Table 1) and vibration levels (Table 2). High vibration and leakage before repair likely contributed to increased internal friction and heat generation. The simultaneous reduction across all three parameters (vibration, leakage, and temperature) confirms that the repair addressed the root causes holistically. Moreso, the key Implications of the reduction in temperature are extension of life of the component. Improved efficiency:, enhanced safety and operational reliability The transition from severe thermal stress to stabilized temperature, as indicated in the remarks, validated the effectiveness of the maintenance strategy employed. These findings reinforced the importance of integrating temperature monitoring with vibration and leakage analysis in predictive maintenance programs for rotating equipment.

Temperature Measurements of Critical Components

Temperature distribution across critical components provided valuable insight into the thermal behaviour and mechanical health of the crude oil transfer pump. Figure 4 showed a comparative graphical analysis of the seal face and bearing temperatures before and after repair

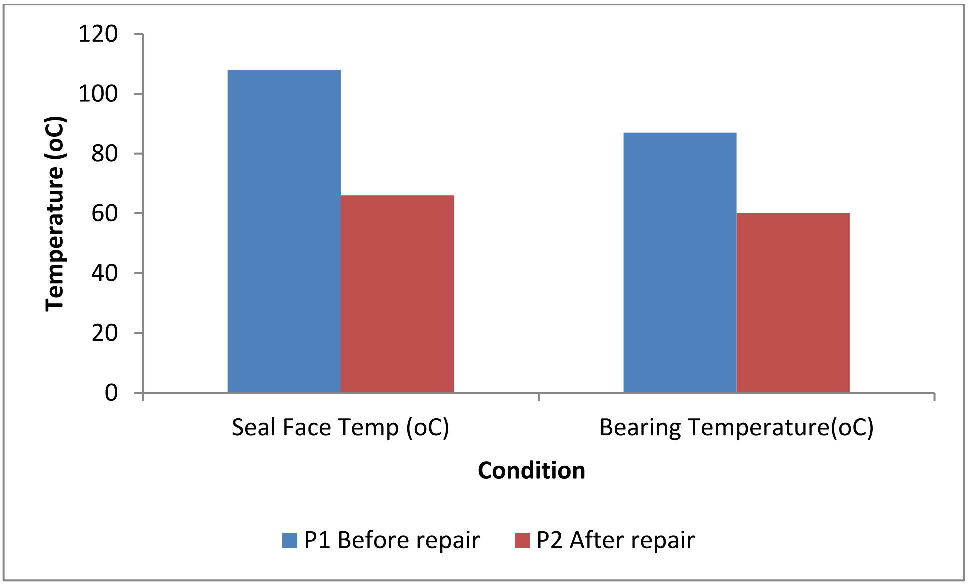

Figure 4: Temperature measurements of critical components of the crude oil transfer pump

As illustrated in Figure 4, the pump operated under severe thermal stress prior to repair. The mechanical seal face temperature reached 108°C, while the bearing temperature was recorded at 87°C. These elevated temperatures are of particular concern for a crude oil transfer pump, where the fluid's high viscosity and potential for abrasives could exacerbate frictional heat generation. Such high thermal loading often resulted from misalignment, worn bearings, degraded mechanical seals, or insufficient lubrication conditions that were evidently present before the intervention.

After the repair works, a significant improvement in thermal performance was evident. The seal face temperature decreased to 66°C, and the bearing temperature dropped to 60°C. This substantial reduction brings both critical components well within safe and recommended operating temperature ranges for centrifugal pumps handling crude oil.

Furthermore, figure 4 clearly demonstrated the effectiveness of the repair in mitigating thermal distress. The marked decrease in seal face temperature is especially important because mechanical seals are highly sensitive to heat. Excessive temperatures could cause thermal distortion of the seal faces, vaporization of the lubricating film, and premature seal failure issues that commonly lead to increased leakage in crude oil service as observed in Table 1.

The reduction in bearing temperature from 87°C to 60°C also indicated improved lubrication conditions and reduced internal friction. Lower bearing temperatures minimize the risk of lubricant oxidation and extend bearing service life significantly (Harris and Kotzalas, 2007).This thermal improvement correlated strongly with the reductions observed in leakage rate (80%) and vibration level (61%). The combined effect suggested that the repair successfully resolved underlying mechanical issues such as shaft misalignment, bearing wear, and seal degradation. In the context of crude oil transfer pumps, where reliability is critical due to continuous operation and hazardous fluid properties, such improvements are vital for operational safety, environmental protection, and cost efficiency. The results presented in Figure 4 reinforce the value of multi-parameter condition monitoring (vibration, leakage, and temperature) in predictive maintenance strategies for critical rotating equipment in the oil and gas industry.

Relationship between Component Temperatures and Leakage Rate

To further understand the interdependencies among key performance parameters of the crude oil transfer pump, Figures 5 and 6 presented the correlation between operating temperatures of critical components and the pump's leakage rate before and after repair.

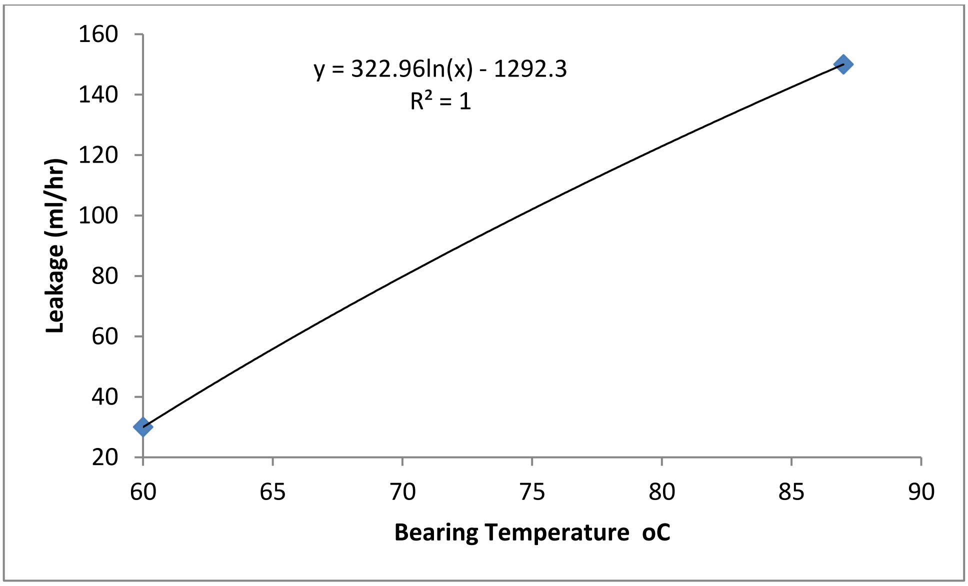

Figure 5: Bearing Temperature (°C) versus Leakage Rate

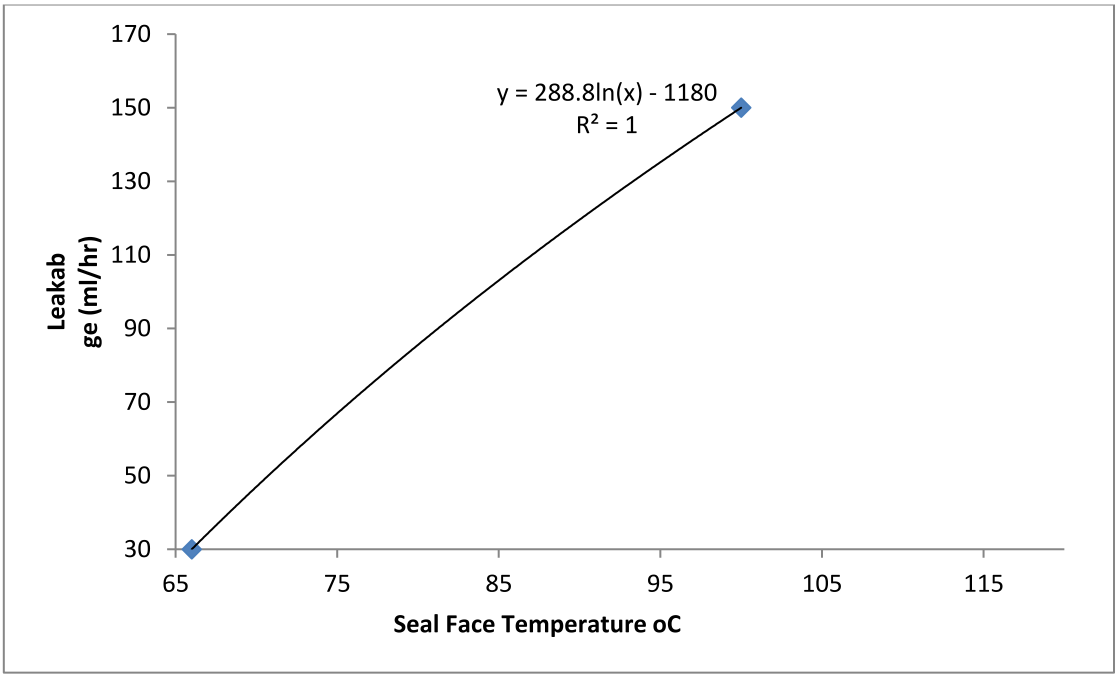

Figure 6: Seal Face Temperature (°C) versus Leakage Rate

As shown in Figure 5, a strong positive correlation existed between bearing temperature and leakage rate. Before repair, the pump exhibited a high leakage rate of 150 ml/hr corresponding to an elevated bearing temperature of 87°C. This combination indicated that excessive internal leakage was accompanied by increased frictional losses and heat generation within the bearing assembly. High leakage could lead to loss of lubrication film, increased radial loads, and consequent rise in bearing temperature.

Following the repair intervention, both parameters improved markedly, with leakage reducing to 30 ml/hr and bearing temperature reducing to 60°C. The downward shift observed in Figure 5 demonstrated that the maintenance activities effectively restored proper bearing clearance, alignment, and lubrication conditions, thereby reducing both heat generation and fluid loss simultaneously

Figure 6 revealed an even stronger relationship between seal face temperature and leakage rate. Prior to repair, the mechanical seal face operated at a critically high temperature of 108°C while the pump experienced a leakage rate of 150 ml/hr.

Such elevated seal face temperatures are known to cause thermal distortion, warping of seal faces, and degradation of the lubricating film, which directly contributed to increased leakage, a common failure mode in crude oil transfer pumps (John , 2019). High temperatures create uneven thermal expansion across the seal faces, leading to coning or warping. This distortion disrupts the critical hydrodynamic lubricating film, resulting in direct face contact, accelerated wear, and higher leakage rates. In crude oil applications, where fluids often contain abrasives and operate under demanding conditions, this failure mechanism is particularly prevalent and could rapidly escalate operational risks

After repair, the seal face temperature decreased to 66°C alongside the substantial reduction in leakage to 30 ml/hr. This significant improvement, clearly visible in Figure 6, indicated successful restoration of the mechanical seal's integrity, proper face loading, and cooling conditions.

Both Figures 5 and 6 revealed a clear positive linear trend, indicating a strong association between higher component temperatures and increased leakage rates. The repair intervention achieved simultaneous reductions of 80% in leakage rate, 31% in bearing temperature, and 39% in seal face temperature. This coordinated improvement suggested that mechanical defects such as shaft misalignment, bearing wear, and seal degradation were common root causes driving both elevated temperatures and excessive leakage. The relationships illustrated in Figures 5 and 6 demonstrated the interconnected nature of thermal and leakage performance in rotating equipment. Excessive heat in bearings and mechanical seals accelerates wear, increases internal

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clearances, and promotes fluid leakage. Conversely, high leakage reduces lubrication effectiveness, further elevating temperatures and creating a self-reinforcing failure cycle (Marscher, 2000).The repair successfully disrupted this cycle.

These findings have significant implications for the oil and gas industry. Monitoring bearing and seal face temperatures could serve as reliable early indicators of potential leakage problems, enabling predictive maintenance. Furthermore, reducing operating temperatures enhances equipment reliability by extending the service life of bearings and mechanical seals, improves operational efficiency through lower energy consumption and reduced product loss, and strengthens safety and environmental compliance by minimizing the risk of hazardous fluid leaks in crude oil service. Collectively, the results presented in Figures 5 and 6 confirm the holistic success of the repair intervention and underscore the importance of implementing multi-parameter condition monitoring (vibration, temperature, and leakage) for critical pumping systems.

The evaluation of the mechanical seal materials revealed notable differences in performance before and after the repair, as presented in Table 4.

Table 4: Material Performance Evaluation

Type of material	Performance before repair	Performance after repair	Remark
Carbon Seal Face	Moderate wear	Improved	Suitable but less durable
FKM Elastomer	Stable	Stable	Better performance

The carbon seal face exhibited moderate wear prior to repair. This degradation was likely a primary contributor to the excessive leakage rate of 150 ml/hr recorded under the pre-repair condition (P1) in Table 4. Following the repair, the surface condition of the carbon seal face showed significant improvement. Carbon seal faces are widely employed in mechanical seals due to their self-lubricating properties, relative softness, and cost-effectiveness. However, they are susceptible to accelerated wear compared to harder counterface materials such as Silicon Carbide (SiC) or Tungsten Carbide (WC), particularly in abrasive or high-pressure operating environments. While carbon remains acceptable for the current application, its relatively lower wear resistance suggests it may not be the optimal choice for achieving extended service life and enhanced long-term reliability.

In contrast, the FKM (Fluoroelastomer/Viton) elastomer demonstrated stable performance both before and after the repair. This stability indicates that the elastomer did not experience significant degradation, swelling, or chemical attack despite operating under high leakage conditions. The substantial reduction in leakage rate from 150 ml/hr to 30 ml/hr post-repair has placed the FKM elastomer in a considerably less aggressive operating environment. Reduced fluid bypass has resulted in lower operating temperatures, decreased chemical exposure, and diminished mechanical stress on the elastomer. Consequently, although the material exhibited stability prior to repair, its long-term reliability and expected service life have been markedly enhanced due to the improved operating conditions achieved through the repair. However, the repair intervention successfully enhanced the performance of the mechanical seal assembly. The carbon seal face benefited directly from surface restoration, while the FKM elastomer demonstrated robust material compatibility and is now operating under more favourable conditions, thereby supporting improved reliability of the sealing system

Comparative Analysis of Pump Performance Parameters

Table 5 shows a comprehensive comparative analysis of the key performance parameters of the crude oil transfer pump before and after the repair intervention. The table quantifies the improvements achieved across vibration, temperature, and leakage rate.

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Table 5: Comparative analysis of parameters before and after correction

Parameter	Before	After	Improvement (%)
Vibration (mm/s)	8.9	3.5	60.7
Temperature (°C)	108	60	42
Leakage (ml/hr)	150	30	80

As shown in Table 5, the repair intervention produced substantial improvements across all monitored parameters. Vibration level decreased from 8.9 mm/s to 3.5 mm/s, which represented a 60.7% improvement. The critical seal face temperature reduced from 108°C to 60°C, and achieved a 42% improvement. Most notably, the leakage rate dropped dramatically from 150 ml/hr to 30 ml/hr, which corresponded to an 80% improvement**.**

Moreso, the results demonstrated consistent and significant enhancement in the pump's mechanical and hydraulic performance. The highest improvement was recorded in leakage rate (80%), followed by vibration (60.7%) and temperature (42%). These reductions indicate that the repair successfully addressed the root causes which were primarily misalignment, bearing wear, and seal degradation , that were simultaneously affecting vibration, thermal behaviour, and sealing integrity. The comparative analysis confirms the overall effectiveness of the maintenance intervention, transforming the pump from a high-vibration, high-temperature, and high-leakage condition to an acceptable and stable operating state. This multi-parameter improvement is expected to enhance equipment reliability, reduce operational costs, and minimize environmental risks associated with crude oil handling.

Graphical Comparative Analysis of Pump Performance Parameters

The Figure 7 provides a visual comparative representation of the key performance parameters of the crude oil transfer pump before and after the repair intervention. This multi-parameter bar chart enables easy evaluation of the effectiveness of the maintenance works across vibration, temperature, and leakage rate.

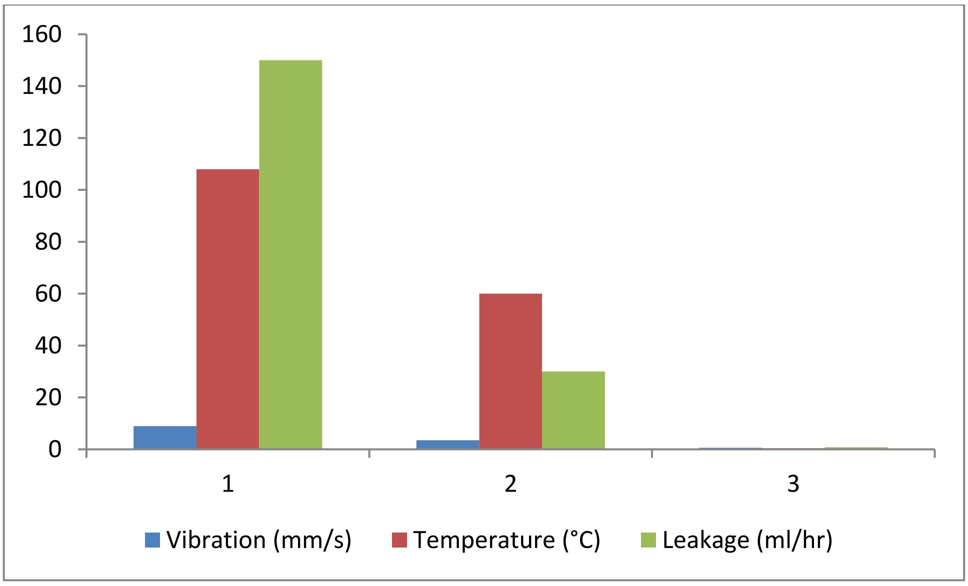

Figure 7: Comparative analysis of parameters before and after correction

As illustrated in Figure 7, all three critical parameters showed remarkable improvement following the repair intervention. Before repair, the pump exhibited high vibration of 8.9 mm/s, elevated seal face temperature of

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108°C, and critical leakage rate of 150 ml/hr. These values indicated poor mechanical condition, characterized by excessive dynamic forces, thermal stress, and fluid loss. After the repair, the parameters improved significantly to 3.5 mm/s for vibration, 60°C for temperature, and 30 ml/hr for leakage rate. The graphical comparison in Figure 7 clearly highlighted the magnitude of improvement achieved.

The percentage improvements for each parameter were calculated using the formula:

$$\text{Improvement (\%)} = \frac{(\text{Before Repair} - \text{After Repair})}{(\text{Before Repair})}) \times 100 \quad (4)$$

Vibration reduced from 8.9 mm/s to 3.5 mm/s which revealed 60.7% improvement, Temperature: reduced from 108°C to 60°C which also showed 42% improvement and Leakage Rate reduced from 150 ml/hr to 30 ml/hr which demonstrated 80% improvement

Figure 7 provided compelling visual evidence of the holistic success of the repair intervention. The most significant improvement was recorded in leakage rate (80%), followed by vibration (60.7%) and temperature (42%). This variation in improvement levels indicated that while the repair effectively addressed the primary failure mechanisms, the response of individual components differed. The simultaneous reduction across all three parameters confirmed that the repair successfully resolved the common root causes, primarily shaft misalignment, bearing wear, and mechanical seal degradation. The substantial decrease in leakage rate reflects restored sealing integrity, while reductions in vibration and temperature indicated improved mechanical stability and reduced internal friction.

Figure 7 reinforced the findings presented in Tables 1-5 and Figures 1-6 and demonstrated that the maintenance intervention achieved comprehensive performance recovery and conclusively, the collective improvements observed across vibration, temperature, and leakage parameters provided strong evidence of a highly successful maintenance intervention. The repair has transformed the pump from a degraded, high-risk operating state to a stable and efficient condition. These enhancements were expected to result in improved reliability, reduced energy consumption, lower maintenance frequency, and extended Mean Time Between Failures (MTBF).The synergistic nature of the improvements is particularly noteworthy: the reduction in leakage directly contributed to lower operating temperatures, which in turn supported reduced vibration levels, illustrated the interconnectedness of these failure modes in mechanical seal systems.

Proposed Mitigation Strategy

a. **Precision Alignment and Foundation Integrity**
    1. Mandatory laser alignment to within 0.05 mm/100 mm.
    2. Elimination of soft foot conditions.
    3. Regular foundation and baseplate integrity checks.
b. **Advanced Sealing System Upgrade**
    1. Upgrade to Carbon vs Silicon Carbide seal faces.
    2. Retain FKM (Viton) secondary seals or upgrade to FFKM (Kalrez) if operating temperatures frequently exceed 120°C.
    3. Installation of a pumping ring and API Plan **11** flush system for improved seal face lubrication.
c. **Condition Monitoring System**
    1. Installation of wireless vibration sensors and temperature transmitters.
    2. Real-time data acquisition linked to a central monitoring dashboard with predictive analytics.
d. **Operational Best Practices**
    1. Ensure minimum flow recirculation to prevent dry running.
    2. Implement strict startup and shutdown procedures to reduce thermal shock.
e. **Maintenance Interval Optimization**
    1. Shift from time-based to condition-based maintenance using vibration, temperature, and leakage trend data.

CONCLUSION

This study examined the root causes of excessive mechanical seal leakage in crude oil transfer pumps operating in the Niger Delta region and evaluated the effectiveness of corrective maintenance interventions. Through systematic field measurements and comparative analysis of key performance parameters before and after repair, the study established a clear linkage between vibration, thermal stress, material degradation, and seal leakage.

The results demonstrated that the pump in its pre-repair condition (P1) operated under severe distress, evidenced by a critical leakage rate of 150 ml/hr, high RMS vibration velocity of 8.9 mm/s, and elevated seal face temperature of 108°C. These conditions exceeded acceptable industry thresholds and accelerated mechanical seal failure. Post-repair analysis (P2) revealed remarkable improvements: leakage reduced by 80% to 30 ml/hr, vibration decreased by 60.7% to 3.5 mm/s, and seal face temperature decreased by 42ºC to 66ºC. These enhancements brought all critical parameters within acceptable operational limits.

The study further confirmed that excessive vibration, primarily induced by misalignment and soft foot conditions, was a major contributing factor to seal face wear and subsequent leakage. The synergistic relationship observed among vibration, temperature, and leakage underscores the interconnected nature of failure modes in rotating equipment. Material evaluation showed that while the carbon seal face benefited from surface restoration, its moderate wear resistance limits long-term durability. Conversely, the FKM elastomer exhibited excellent stability and performed better under the improved operating conditions.

Conclusively, the corrective interventions which included shaft realignment, soft foot correction, and seal restoration proved highly effective in restoring pump reliability and operational efficiency. The findings validated the hypothesis that targeted maintenance addressing vibration and alignment issues could considerably reduce mechanical seal leakage in crude oil transfer pumps.

RECOMMENDATIONS

1. Conduct extended monitoring (18-24 months) to assess the sustainability of improvements and determine the actual MTBF of the repaired pump.
2. Investigate the long-term performance of advanced seal face materials (e.g., SiC vs SiC or Tungsten Carbide) under Niger Delta crude oil conditions.
3. Examine how variations in crude oil composition (sand content, water cut, viscosity, and API gravity) influence seal degradation and leakage.

4. Develop machine learning-based models using real-time vibration, temperature, and leakage data for early failure prediction

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