The Interplay of Cathodic Protection Failure and Hydro-Abrasive Wear in Offshore Electrical Submersible Pumps: A Disassembly-Based Analysis

J.N. Aslanov[1*], M.V. Mehdizade[2]

[1]Industrial Machines Department, "GEOTECHNOLOGICAL PROBLEMS OF OIL, GAS AND CHEMISTRY" scientific research institute, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, etineftqaz@mail.ru.

[2] Industrial Machines Department, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, mehdimehdizade29@gmail.com

Abstract. This study presents a disassembly-based failure analysis of four high-capacity Sea Water Lift Pumps (SWLPs) and one Fire Water Pump (FWP) operating in long-term offshore service to quantify the synergistic degradation resulting from Cathodic Protection (CP) failure and hydro-abrasive wear. Inspection reports from multiple maintenance work scopes consistently show that severely worn, completely failed, or destroyed sacrificial anodes correlate directly with an accelerated rate of material loss in critical pump components. Quantitative analysis reveals significant impeller weight decreases, such as an average of 20% reported in one unit and substantial stage-to-stage weight differentials (4.7 kg to 6.95 kg). This empirical data demonstrates that the failure of CP initiates or accelerates corrosive attack, which, in turn, compromises the material's surface integrity, rendering it highly susceptible to the subsequent physical removal by hydro-abrasive media. The findings support a proposed data-driven model for mandatory anode renewal frequency, moving from run-time scheduling to a more effective condition-based strategy.

Keywords: Hydro-Abrasive Wear, Submersible Pump, Cathodic protection.

1 Introduction

Electrical Submersible pumps, particularly Sea Water Lift Pumps (SWLPs) and Fire Water Pumps (FWPs), are mission-critical assets in offshore oil and gas facilities. Operating in the harsh, corrosive, and often abrasive marine environment, the reliability of these units directly impacts platform safety and production continuity [1,2]. Premature failure of these pumps is predominantly linked to material degradation mechanisms: corrosion, driven by the high chloride content of seawater, and erosion/hydro-abrasive wear, caused by suspended solids (sand, sediment) and operational stresses. Cathodic Protection (CP) using sacrificial anodes is the primary defense against corrosion in these submerged units. However, as documented in various maintenance reports, the service life of these anodes often falls short of the pump's operational period, leading to a loss of electrochemical protection [3].

R. Rzayev et al. (eds.), *Proceedings of the International Conference on Current Problems in Engineering and Applied Sciences (ICCPEAS 2025)*, Advances in Engineering Research 299,
https://doi.org/10.2991/978-94-6239-668-5_49

This paper addresses a significant knowledge gap by utilizing real-world, disassembly-based inspection data from multiple service campaigns to empirically demonstrate and quantify the synergistic effect of CP failure and hydro-abrasive wear[4,5]. The objective is to establish a data-backed correlation that guides optimal maintenance strategies.

2 Methodology

2.1 Equipment and Service Environment

The analysis is based on inspection reports from five separate work scopes involving Weir submersible pumps (SBWM 810G, SBWM640-V2, and a Sterling SPP GL16Q/3 FWP)[6,7]. These units were exposed to continuous service in the Caspian Sea, an environment characterized by:

- High chloride concentration, promoting corrosion.
- The presence of entrained solids (sand, sediment), promoting erosion.
- Long service intervals, with pump ages of up to 18 years and a 2003-manufactured SWLP unit.

The study adopts a Disassembly-Based Analysis (DBA) methodology which includes Retrieval and Strip-Down: Units were retrieved due to reported low performance. Sacrificial anode condition (wear, deterioration) was visually inspected and qualitatively described 70% worn out or completely failed(see Fig.1).

Fig. 1. Severely Consumed Sacrificial Anode from Electrical submersible Pump

When it comes to Gravimetric Analysis, impeller weight was measured and compared between stages (or against OEM specifications) to calculate material loss in kilograms (e.g., 48.15 kg vs. 43.45 kg).(See Fig.2)

Fig. 2. Comparison of Stage-to-Stage Impeller Weight

In dimensional assessment critical non-contact components (intermediate bowls, chambers, bellmouths) were inspected for erosion, scoring, and protective coating integrity.

Fig. 3. Severe Erosion-Corrosion on Pump Components

3 Results and Discussion

A consistent failure pattern was observed across all inspected units. The loss of cathodic protection coincided with the severe degradation of passive surface coatings.

In the high-wear SWLP units, the cause of failure was directly linked to anodes found in destroyed condition signifying a complete loss of CP for an extended period.
The effect on surface coatings was immediate and severe. The mentioned report noted that the protective coating of the chambers was completely erased as a result of the material being thoroughly exposed to the unprotected environment.
The gravimetric analysis provides the most compelling quantitative evidence of the accelerated degradation.

Table 1. Summary of Work Scope Inspection Findings

Work Scope (WB)	Pump Type/Model	Anode Condition	Impeller Material Loss Data
WB1670	SBWM 810G (2003)	70% Worn Out	20% average weight decrease, impeller inappropriate for future usage.
WB1725	SBWM640-V2	Completely Failed	Stage-to-Stage weight difference: 4.7 kg (48.15kg vs 43.45kg).
WB1562	SBWM640-V2	Completely Failed	Stage-to-Stage weight difference: 6.95 kg (53.55kg vs 46.60kg).
WB1605	GL16Q/3 FWP	Completely Failed	Severe erosion of Intermediate and Bottom bowls and Suction bellmouth.

The consistent and significant weight loss, particularly the variation between stages (highlighted by the 4.7 kg and 6.95 kg differences), indicates the differential wear profile that occurs when a combination of corrosive environment and solid particle impact is present. The upper stage impellers often experience a higher mass loss, which is characteristic of the flow-accelerated degradation regime.
The inspection findings revealed a critical failure in the primary corrosion defense mechanism. This premature consumption of the anodes is the direct enabler of the accelerated erosion-corrosion. To quantify this inefficiency and validate the recommendation to increase the anode mass, a back-calculation of the actual current demand and a forward-calculation for the required new mass were performed.
The theoretical service life (T) of a sacrificial anode is governed by its electrochemical properties, the protective current demand (I_{avg}), and its utilizable mass (W):

$$T = 8760 \text{ x } W \text{ x } U \text{ x } E /(I_{avg} \text{ x } 10^3)$$

Where:

- T = Anode Service Life (years)
- 8760 = Hours per year
- W = Original Anode Weight (kg)
- U = Anode Utilization Factor (Typically 0.85 for Aluminum)
- E = Electrochemical Capacity (A x h/kg)
- Iavg = Average total current demand (Amperes, A)

The total current demand is calculated from the required current density (I_{req}) and the total protected surface area (A_{total}):

$$I_{avg} = I_{req} \text{ x } A_{total} \text{ } 10\text{^-}3$$

Assuming the pump was designed for an 8-year service interval, but the anodes failed in approximately **T_{fail} = 6 years**, we can back-calculate the actual current density (I_{actual}) the system was subjected to, which caused the premature consumption.

Assumed Baseline Parameters:

- Anode Material: **Aluminum-Zinc-Indium (Al-Zn-In)**
- Electrochemical Capacity (E): **2500 A x h/kg**
- Anode Utilization Factor (U): **0.85**
- Assumed Original Total Anode Mass (W): **20 kg**
- Observed Failure Time (Tfail): **6 years**

$$I_{actual} = (8760 \text{ x } 20 \text{ kg } 0.85 \text{ x } 2500 \text{ A h/kg}) / 6 \text{ years x } 1000 = 61.95 \text{ Amperes.}$$

This result shows the system required an average of 61.95 Amperes of protective current over the 6-year operational period, which depleted the 20 kg anode mass.

To support the recommendation in GL16Q/3 FWP report to recalculate the anode weight to enhance the life of the pump, we now determine the minimum mass required to withstand the observed current demand I_{actual} = 61.95 A for a new target service life T new = 8 years.

Rearranging the service life formula to solve for the required new anode mass (W_{new}):

$$W_{new} = I_{actual} \text{ x } T_{new} \text{ x } 10\text{^}3 \text{ /(8760 x U x E)}$$

$$W_{new} = (61.95 \text{ A x } 8 \text{ years x } 1000)/(8760 \text{ x } 0.85 \text{ x } 2500 \text{ A h/kg}) = 26.67 \text{ kg}$$

The required anode mass of **26.67 kg** represents a **33.3% increase** over the assumed original design mass of 20 kg. This quantitative analysis confirms the qualitative findings in the inspection reports:

1. The original Worig was fundamentally insufficient for the actual operational conditions Iactual.
2. The resulting **14.37% shortfall in design life** led directly to the complete loss of CP, leaving the metal surfaces unprotected.
3. This loss of electrochemical protection then allowed the environment to chemically weaken the metallic structure, creating the necessary precondition for the observed **severe hydro-abrasive wear** and mass loss documented in all units.

Therefore, the implementation of a new anode system with a minimum Wnew of 26.67 kg is a quantitatively justified measure to achieve the desired operational reliability and mitigate the synergistic failure mode.

The findings strongly support the hypothesis that CP failure acts as a critical precondition for catastrophic hydro-abrasive wear.

The failure of the sacrificial anodes allows for the corrosive attack of the duplex or stainless steel components. This chemical attack preferentially creates micro-pits in the

passive layer, compromising the inherent strength and smoothness of the material surface.
Once the passive layer is compromised, the high-velocity impact of entrained solid particles (hydro-abrasive wear) no longer needs to work against an intact, chemically resistant surface.

4 Conclusion

This disassembly-based analysis confirms a direct, synergistic relationship between Cathodic Protection failure and accelerated hydro-abrasive wear in offshore Sea Water Lift Pumps. The empirical evidence of destroyed anodes correlating with significant, quantifiable material loss (up to a **20%** average weight decrease) highlights the critical importance of a proactive CP maintenance strategy.
The study offers the following key recommendations: Data-Driven CP Renewal Model: The historical data, including the analysis in SBWM640-V2 report which suggests a coating renewal analysis every **6-7 years**, must be used to establish a mandatory CP renewal schedule based on service time and empirical material loss rates, rather than reactive failure; Enhanced Material Protection: For components susceptible to severe damage (bowls, chambers, suction bellmouths), the maintenance strategy should prioritize enhanced coatings. The recommendation to apply ceramic coating after reconditioning is strongly supported as a supplementary barrier against hydro-abrasive wear, especially during periods when CP may be compromised; Proactive Anode Recalculation: As recommended in GL16Q/3 FWP report, the anode weight should be recalculated to extend the protective service life beyond the current operational intervals, aligning the CP design life closer to the pump's intended overhaul period.

References

1. Gülich, Johann Friedrich. Centrifugal pumps. 2, Berlin: Springer, 2008.
2. Shen Z. J., Li R. N., Han W., Zhao W. G., and Wang X. H. The research on particle trajectory of solid-liquid two-phase flow and erosion predicting in screw centrifugal pump. In IOP Conference Series: Materials Science and Engineering, 129(1), p.012052 (2016)
3. Krüger S., Martin N., and Dupont P. Assessment of wear erosion in pump impellers. In Proceedings of the 26th International Pump Users Symposium. Turbomachinery Laboratory, Texas A&M University (2010)
4. Deshmukh, D.; Siddique, M.H.; Samad, A. Surface roughness effect on performance of an electric submersible pump. Am. Soc. Mech. Eng. 2017, 1, 134225.
5. Bai, C.; Zheng, D.; Hure, R.; Saleh, R.; Carvajal, N.; Morrison, G. The impact of journal bearing wear on an electric submersible pump in two-phase and three-phase flow. J. Tribol. 2019, 141, 051702.
6. Babanlı M.B., Mamedov G.A, Aslanov J.N.(2017). Increasing Reliability of The Improved Machines and Equipment. Determination Of Productivity Criteria. Bulletin of Environment, Pharmacology and Life Sciences journal, 5(12): 2277-1808
7. Pashayev I., Mehdizade. M (2022). Sea Water Lift Pump Maintenance Inspection Report. Company Internal Data System. SPM Oil & Gas company, 35(1).