PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (3) 747-754 Mar. 2025

Decade of Electrical Submersible Pumps Failures: Case Study on Performance and Optimization

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ABSTRACT: Electrical submersible pumps (ESPs) are widely used as an artificial lift technique utilized for oil production worldwide. Run and pull reports and production tests were analyzed. The paper also recommends mitigation strategies for determined failures to prolong an ESP run life. Electrical failures are the most common ESP failures mainly due interruptions and discontinuations in electricity supply. Technical and operational failures because of improper ESP pump selection and planning. Employing ESP system design that takes into consideration reservoir potential and reservoir fluid and rock properties, while also accounting for the economic factor, can prevent these failures. Mechanical failures are mostly material dependent. It is therefore important to properly select material that is compatible and corrosion resistant to prevent grounded cable and motor and hole in production tubing. Suitable material implementation prolongs run life of an ESP assembly. Employing the proper material prevents component failures. Implementing suitable scale inhibitor to deal with scale depositions as well as utilizing gravel pack for sand screening assists in reducing ESP failures. Regular well cleaning may also reduce pump flow passages being stuck. Some ESP assembly failures are related and can cause other failures. Thus, early prevention of such failures results in failures discontinuation.

DOI: https://dx.doi.org/10.4314/jasem.v29i3.8

Cite this Article as: MAHMUD, W. M; JALUTA, A. M (2025). Decade of Electrical Submersible Pumps Failures: Case Study on Performance and Optimization. *J. Appl. Sci. Environ. Manage.* 29 (3) 747-754

Dates: Received: 30 September 2024; Revised: 11 January 2025; Accepted: 03 March 2025; Published: 31 March 2025

Keywords: Artificial Lift; Electrical Submersible Pump (ESP); ESP Review; Case Study; ESP Failures; ESP Mitigation

Hydrocarbon production requires energy to lift reservoir fluids to surface. During early production phase, most hydrocarbon wells flow naturally, due to reservoir natural flow drive mechanisms and are referred to as naturally flowing wells. In a naturally flowing well there is enough energy stored in a reservoir to flow produced fluids to surface (Ben Mahmud *et al.*, 2020, Goswami, *et al.*, 2015). However, reservoir natural energy depletes over production time. Therefore, as a result, reservoir fluids require an external method to be lifted to surface. Rapid increase in energy demand has encouraged oil producers to search for methods to improve production (Goswami, *et al.*, 2015). Most oil wells ultimately require artificial lift when reservoir energy becomes insufficient to sustain economic production rates or when increased output is needed for financial reasons (Ben Mahmud *et al.*, 2019). Several artificial lifting techniques are available to select from (Takacs, 2017) to produce fluids from wells already dead or to increase production rate from flowing wells. Artificial lift techniques can be divided into two main categories: mechanical lifting through pumps and gas lift in which high-pressure gas is injected into a reservoir formation for supplementing formation gas to lift

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well fluids. Pumps are subdivided into positive displacement pumps such as sucker rod pumps and progressing cavity pumps (PCP) and dynamic displacement pumps such as electrical submersible pumps (ESP) and hydraulic jet pumps. Moreover, there are other uncommonly used artificial lift methods such as hydraulic piston and plunger lift. ESP systems can be installed not only in conventional wells but also in deep, deviated wells. They are adaptable to various bottom-hole pressures, gas-oil ratios (GOR), bubble-point pressures, and water cuts (Mahmud *et al*., 2022). However, ESP components are vulnerable to unexpected failures due to well conditions, electrical issues, improper design and installation errors (Takacs, 2017). Harsh conditions such as corrosion, high temperatures, high-viscosity fluids, formation gas, sand production and scaling (Mahmud *et al*., 2017) further contribute to ESP failures. Moreover, manufacturing and human errors may also be contributing factors to further ESP failures. ESP failures can be categorized into three main types: electrical, mechanical, and operational. Electrical failures include cable and motor issues, overloads, and connection severance. Mechanical failures involve component breakage, corrosion, dislocation and leakage. Operational failures are related to temperature, pressure, gas, solids, and deviations in well trajectory (Fakher *et al*., 2021). Additionally, various ESP system failures can significantly reduce pump run life. Therefore, a thorough investigation of common ESP failures and the implementation of effective mitigation strategies are essential for extending the lifespan of wells producing hydrocarbons through ESP systems. Monitoring is a crucial factor in extending an ESP's run life. Vibration monitoring can help prolong ESP operation, as increased vibrations often indicate issues such as sand production, axial thrust imbalances, motor overheating and pump wear (Baillie *et al*., 2001). Thus, vibration analysis serves as an effective tool for early failure detection, preventing premature ESP failures. Another valuable approach involves establishing standardized practices for collecting, tracking and sharing ESP run-life and failure data (Alhanati *et al*., 2001). This method relies on two key elements: a standardized dataset and a uniform nomenclature for coding ESP failures. By categorizing failures based on mode, cause, and contributing factors, ESP reliability can be enhanced by reducing uncertainty in run-life predictions. However, for accurate outcomes, data must be derived from large and consistent datasets. Accurate design, proper installation and continuous monitoring are essential for optimizing an ESP's run life. A practical checklist (Baillie, 2002) helps identify issues in the three major ESP components: mechanical, electrical and hydraulic. Based on these findings, targeted solutions can be implemented throughout the ESP's life cycle, from design to installation and operation. Consequently, using this checklist can help prevent premature failures and maximize ESP performance.

ESP failures caused by sand production and high GOR can be minimized, thereby extending ESP run life, by using a shrouded motor, XGC gas handler, slim-hole pump and abrasion-resistant pump materials (ARS pump, ARM-COM pump) (Mubarak *et al*., 2003). A combination of field data analysis and laboratory experiments was conducted to investigate common ESP failures and challenges (Shimokata and Yamada, 2010). Cable quality issues and scale buildup, such as asphaltene and calcium carbonate ($CaCO_2$), were identified as major failure causes. These can be mitigated by improving ESP cable quality and injecting xylene to dissolve scale deposits. To further analyze ESP failures, the Dismantle Inspection Failure Analysis (DIFA) approach was proposed (Al-Sadah, 2014). This method identified well conditions, installation errors and material reliability as key failure factors. Addressing these issues significantly improves ESP performance. Moreover, high-salinity reservoir fluids and corrosive environments contribute to premature ESP failures due to corrosion and erosion (Brahmi, 2016). Installing a freshwater injection line and upgrading ESP components including housing material, cable, motor, motor lead cable (MLC), protector and pump can mitigate these risks. Moreover, optimizing surface facilities, such as Variable Speed Drives (VSDs), generators and control panels further reduces ESP failures. A stage-by-stage analysis approach was proposed to enhance the understanding of gas-effect behavior and its impact on control pressure values and gas volumes in an ESP system (Ramirez and Martinez, 2017). Wells producing large volumes of free gas require additional pump stages to ensure fluids are lifted at the desired operating flow rates. Optimization of ESP system design, operation, diagnostics, failure analysis and performance were studied for deep wells operating at high temperatures, elevated GOR, and high concentrations of CO_2, N_2, and H_2S (Oliva *et al*., 2017). This study utilized root cause analysis (RCA), field tests, and ESP data analysis. Proper ESP installation, selecting suitable materials and coatings for cables and implementing scale removal techniques were found to significantly extend the system's run life. Inorganic scale buildup in ESP systems installed in offshore oil wells was studied using X-ray analysis, laboratory experiments and corrosion and sensitivity tests (Garcia-Olvera *et al*., 2018). The study recommended monitoring discharge and intake pressures, motor temperature and power to prevent potential ESP failures. Moreover, a combination of chemical and mechanical treatments was suggested for scale removal (Mahmud & Ermila, 2020). Electrical discharge can cause motor bearing failure in ESP systems. Finite element analysis (FEA) and computational fluid dynamics (CFD) were used to study electrical discharge and electric field distribution within ESP motor bearings (Ye and Wilcox, 2018). Reducing ESP failures requires a balanced power system, improved power quality, enhanced insulation materials and reduced voltage stress. The role of data management systems (data input and quality), fluid characterization, DIFA, operational procedures and real-time surveillance in ESP run life was also investigated and implemented (Villalobos Leon *et al*., 2018) leading to reduced ESP failures by 86% and increased survival probability by 66.6%. An integrated approach combining ESP design improvements, real-time monitoring and DIFA was developed to extend ESP run life (Almajid *et al*., 2019). Upgrading ESP metallurgy, implementing advanced gas handling systems and developing real-time data analytics software contributed to increased average run life while limiting repetitive trips and failures. A troubleshooting guide was proposed to diagnose the effects of worn pumps, broken shafts, well sanding, gas blockages and sensor data loss on key operating parameters such as PIP, PDP, Q, WHP, motor temperature and motor amperage (Nunez *et al*., 2020). The guide introduced tests and remedies that reduced the failure index by 60%, improving ESP reliability. The effects of viscosity and two-phase flow on ESP performance were analyzed using experimental tests, analytical methods, and CFD simulations (Liu *et al*., 2020). Numerical predictions of ESP performance were conducted using well-specific cubic models to evaluate fluid property impacts (Minemura and Uchiyama, 1993; Minemura *et al*., 1998). Higher API gravities, GORs and pump intake pressures were found to enhance pump speed whereas higher water cuts decreased it (Joseph *et al*., 2020). AI based systems were implemented to mitigate electrical, mechanical and operational ESP failures by optimizing material selection for various downhole environments, improving pump design for efficiency and reliability and enabling real time monitoring (Fakher *et al*., 2021). Moreover, statistical ESP failure data evaluation and DIFA identified root causes of ESP failures, with electrical and motor failures being the most common, followed by gas locking (AlBallam *et al*., 2022).

MATERIALS AND METHODS

Table 1 categorizes all potential ESP assembly failures, including electrical, mechanical, operational failures and improper selection, along with their sub-classifications. While electrical, mechanical, and operational failures have been extensively discussed (Fakher *et al*., 2021), this study introduces "improper selection" as an additional failure category. The protector plays a crucial role in preventing water intrusion into the motor, which can otherwise lead to motor burnout. A water-filled protector can also cause the motor to burn out and become grounded.

To analyze common ESP failures and propose solutions to extend an ESP run life and enhance production, this study collected run and pull reports and production test data from six wells between 2013 and 2023.

Table 1: Categories of potential ESP assembly failures along with their sub-classifications ESP Failures

Electrical	Mechanical	Well Conditions	Improper Selection
- Power quality - Cable - Motor - Overloading - Connection Severance	- Component breakage - Corrosion - Dislocation - Leakage - Vibration	- Operating temperature - Pressure - Overheating - Gas production - Sand production - Scale - Deviated wells	- Design defects - Information defects - ESP in stock

RESULTS AND DISCUSSION

The targeted field area spans 250 km² and contains 24 wells, with a maximum depth of 8,860 feet. The field's stock tank oil originally in place (STOOIP) is 415 MMSTB, with fluid expansion and water injection serving as the primary recovery mechanisms. To date, approximately 77 MMSTB have been cumulatively produced. This study focuses on the performance of ESP systems in six wells from 2013 to 2023. Unless otherwise stated, all discussions pertain to this period. Field data, including run and pull reports and production test results, were analyzed for each well. Table 2 provides details on drilling, completion and ESP installation dates for these six wells. Table 3 presents the failures observed in the six selected wells during the study period. Each 'X' indicates the cause of failure and the corresponding number of pullouts.

Table 2: Drilling, completion and ESP installation dates of the six wells

Well #	Drilling	Completion	ESP First Installation
1	November 1963	November 1963	
2	March 1986	July 1986	August 1998
3	January 1991	April 1991	
4	February 1991	June 1991	December 1994
5	January 2001	May 2001	
6	May 2003	June 2003	

Table 3: Number of failures occurring during the targeted period.

Well #/pull out problem	**Electrical fault down hole**	**O.D.H.**	**N.F.T.S.**	**Gas separator (No side play, plugged, and stuck)**	**No flow**
1	X	X	X	X	
2		XX	X		XX
3		X	XX		
4		XX	X		
5					
6		XXX	XX		

Table 3 shows that well #1 experienced the most ESP failures, including electrical issues, Off Down Hole (O.D.H.), No Flow to Surface (N.F.T.S.) and a plugged or stuck gas separator. The pull report indicated that the motor was filled with water upon retrieval, suggesting a wet protector, along with a grounded cable, sand plugging and scale buildup. Well #2 encountered O.D.H., N.F.T.S. and no-flow failures due to electrical component corrosion, a hole in the tubing and sand accumulation in the pump. Well #3 failures were attributed to a grounded motor and cable, as well as a hole in the tubing. An N.F.T.S. failure necessitated an acid squeeze job. Additional failures resulted from a blown or grounded electrical cable, a wet protector, a worn-out pump and tubing leaks. Well #4 experienced a grounded motor and cable, a hard-turning pump shaft and pump blockage due to cement. The tubing also failed a pressure test indicating a leak. Well #5 failures included O.D.H., no flow and a washed-out bleeder pin. Pullouts were required due to a grounded cable, corroded armor and corroded protector housing. No flow was attributed to a tubing leak that prevented fluid from reaching the surface. Well #6 encountered O.D.H. due to various ESP system issues leading to a grounded motor. Sand plugging prevented the pump shaft from turning, the protector chambers were water-filled and the gas separator was stuck. Additional O.D.H. failures resulted from a wet protector, corroded tubing, scale buildup in the gas separator, a stuck pump shaft and collapsed production tubing joints. N.F.T.S. failures were linked to tubing leaks and protector chamber issues, with water and mixed fluids found in the upper, center and lower chambers. After the sixth pullout, the pump was noisy, and the check valve contained scale.

Multiple causes of ESP failures were identified, primarily linked to well conditions, electrical and mechanical failures and improper design. However, corrosion emerged as the most prevalent issue across all studied wells. Pullout data revealed that corrosion affected carbon steel tubing and electrical components such as the motor, cable and armor. For example, ESP system failures due to tubing leaks resulted in a N.F.T.S. To mitigate this, corrosion-resistant tubing materials like Reda alloy could be installed, and cable armor could be upgraded from galvanized steel to Monel, a copper-nickel alloy. Therefore, injecting corrosion inhibitors compatible with utilized materials and reservoir fluids into the casing annulus or using higher-grade tubing materials such as Cr-Mo instead of carbon steel could help reduce corrosion and extend ESP run life (Shimokata and Yamada, 2010). Alternatively, replacing carbon steel tubing with martensitic stainless steel alloy (S_{13} Cr) has been suggested as an effective corrosion mitigation strategy (Brahmi, 2016). For galvanized armored cables, Monel was used as the highest-grade corrosion-resistant material to protect ESP motors and other components. Housing materials were upgraded from carbon steel to Reda alloy and tandem protectors were introduced to resist corrosion and prevent water contamination of the motor. Another common well condition issue contributing to ESP failure, particularly in wells #1 and #6 was scale deposition in the gas separator and check valve. Scale prevention can be achieved by injecting scale inhibitors into the formation (Shimokata and Yamada, 2010). If inhibitor treatments prove ineffective, water jetting can be used to remove buildup after pulling the ESP assembly (Fakher *et al*., 2021). Moreover, well conditions should be assessed during pump replacements and any scale precipitation should be removed. Sand accumulation also led to pump failures in wells #1, #2 and #6 as sand was found inside the pumps after ESP units were pulled out. To mitigate sand-related problems, installing a gravel pack or screen could help protect the ESP system from sand intrusion (Baillie, 2002).

Electrical failures in ESP systems can originate from both downhole and surface facilities. Downhole failures typically involve electrical components such as the electric cable, stator or motor downhole sensor (Fakher *et al*., 2021). Motor grounding was observed in wells #3, #4, and #6 while motor overheating and irregular voltage were detected in well #2. Moreover, prolonged well shutdowns during the 2020 COVID-19 pandemic led to scale deposition on pumps. Switching on ESP units at high frequencies (50 Hz or 60 Hz) can also burn the motor, emphasizing the importance of using a VSD for a soft start. Other electrical failures, particularly cable-related issues, occurred in wells #2, #3, #4, #5, and #6.

Mechanical failures are generally linked to the moving components of ESP downhole equipment (Fakher *et al*., 2021). A recurring issue in all wells was leakage in the protector, which, if penetrated by well fluids, could lead to motor failure. Wet protectors and grounded motors were identified in wells #1, #3, #4, #5, and #6. A broken shaft was encountered in well #4. Sand production, a major contributor to mechanical failures, caused plugging and stuck gas separators in wells #1 and #6. Sand-related failures can be mitigated by upgrading pump metallurgy and design, using larger mixed-flow impellers, or installing a gravel pack or screen (Baillie, 2002). Additional mechanical failures included a noisy pump in well #6, a pump plugged by cement in well #4, hard-turning pumps in wells #1 and #6, and stuck pumps in wells #1, #2, and #6. Pump failures accounted for approximately 10% of total ESP failures in the studied wells, nearly half the percentage reported by Joseph *et al*. (Joseph *et al*., 2020). Failures in components attached to production tubing were also observed. A broken bleeder pin in well #2 caused a N.F.T.S., while a broken and washed-out bleeder pin in well #5 also resulted in flow issues. Component dislocation can lead to multiple failures, especially when the affected part is integral to the ESP string (Fakher *et al*., 2021).

Improper or inaccurate ESP design is a key factor that can reduce pump run life. For example, the D1150N pump installed in well #3, designed to lift oil at rates between 400 and 1,600 BPD, operated in a down-thrust condition due to the well's lower production potential. As a result, the pump was replaced multiple times between 2018 and 2023. In February 2023, a DN-1750 pump was installed in well #3 but continues to operate in down-thrust conditions. Similarly, between August 2021 and December 2022, a D800N pump in well #4 operated under up-thrust conditions. Operating pumps in either up- or down-thrust conditions accelerates wear and damage. A recommended solution is the use of a wide-range operating pump to prevent thrust-related failures. This approach reduces operational costs associated with frequent ESP replacements, workover rig expenses and production losses. Moreover, implementing a VSD instead of a fixed 60 Hz switchboard allows for frequency adjustments, enabling variable pump speeds and flow rates. These two advancements- wide-range operating pumps and VSDs- enhance ESP performance and longevity (Almajid *et al*., 2019). Maximus motors offer flexibility across various ESP applications, as they are variable rated for different operating conditions. Their factory-filled design prevents contamination during transportation and storage, minimizing failures caused by human error and reducing rig time during installation. Despite the importance of downhole monitoring, the ESP systems in the studied wells lacked downhole sensors. This absence prevented early detection of critical failures such as holes in production tubing, worn or plugged pumps, motor overheating, down-thrust issues and solid production (Baillie, 2002; Nunez, 2020). Integrating downhole sensors can significantly improve failure prevention and extend ESP run life.

The overall performance of the ESP systems indicates that the two most common failures were grounded cables and holes in production tubing as shown in Figure 1. Other significant failures included grounded motors, well condition-related issues, corrosion, sand production and scale. Table 4 presents the pump types and their run times (in days) for the six wells during the study period. In well #1, three pumps were installed with run lives of 1,804, 472 and 171 days, respectively, showing a significant decline in run times over time. Production tests in well #2 revealed that the pump operated under both up- and down-thrust conditions which likely contributed to reduced run life. Similarly, in well #3, pumps were replaced three times, indicating recurring failures. In well #4, pump type D725N initially operated within the production range, however, as fluid production exceeded the pump's capacity, up-thrust conditions developed leading to failure due to wear. To address this, pump type D800N was installed between 2021 and 2023 with different stage configurations. However, the pump was still unable to accommodate production surges and up-thrust reoccurred causing further failures. In well #5, pump DN460 ran for 355 days before failing due to a washed-out bleeder. Although both pumps (D475N and D460N) shared the same operating range, D475N required more stages to lift fluids.

Well #6 initially saw a significant increase in pump run life from 419 to 1,812 days for the same pump type. However, run life then dropped drastically to 228 days due to multiple system failures. The pump also operated under up-thrust conditions because production exceeded its designed capacity. In response, a D1150N pump was installed, which initially operated within the correct range. However, another up-thrust event led to the installation of two D800N pumps in 2021 and 2022.

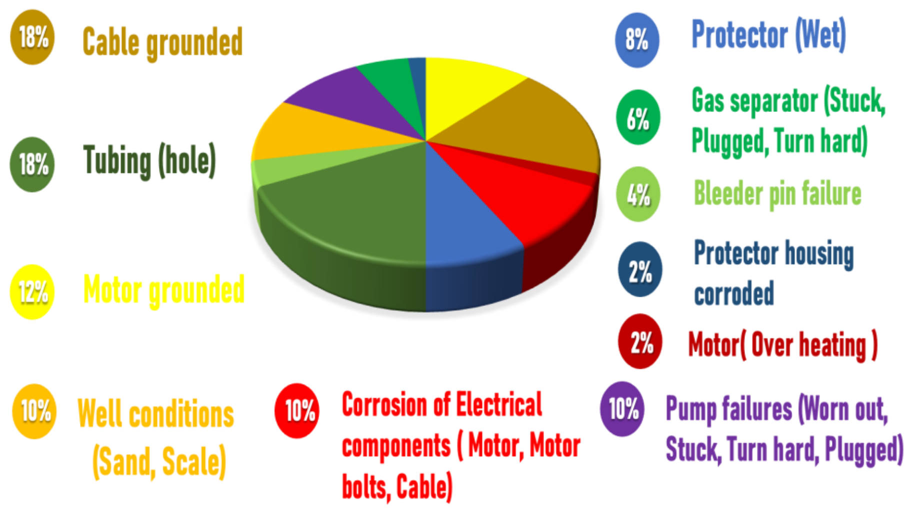

Fig 1: Overall performance of the ESP systems of the six wells.

Table 4: Pump types and run time, in days, for the six wells during the study period.

Well # 1	Pump type	DN 475	DN 460	DN 460			
	Run life	1804	472	171			
	2	DN 1750	DN 1750	DN 1750	DN 1750		
		589	282	165	961		
	3	P2	DN460	D1150N			
		1688	0	619			
	4	DN725	D800N				
		4294	129				
	5	DN475	DN475	DN460			
		782	1398	355			
	6	D725N	D725N	D725N	D1150N	D800N	D800N
		419	1812	228	820	119	253

Conclusions: Electrical failures are the most common in ESP systems primarily due to power supply interruptions. Technical and operational failures frequently result from improper ESP pump selection and planning leading to further mechanical failures because of up and down thrust failures. Mechanical failures largely depend on material quality. Scale deposition and ESP motor overheating are also a major cause of ESP systems failures. Some ESP assembly failures are interconnected potentially leading to further issues. Therefore, early prevention helps mitigate and discontinue failures. Designing an ESP system that accounts for reservoir potential, fluid and rock properties, while also considering economic factors, can help prevent failures. Operational failures can be mitigated through precise and thorough planning. Updated and accurate data are essential for optimal ESP design, along with the installation of a VSD and downhole sensors to maximize pump run life and minimize downtime. Selecting corrosion-resistant materials is crucial to preventing grounded cables, motor failures and production tubing leaks. For example, upgrading metallurgy in ESP components, replacing carbon steel tubing with corrosion-resistant alternatives like Reda alloy and using Monel for cable armor can enhance longevity and performance. Proper material selection reduces component failures while implementing scale inhibitors and gravel packs helps mitigate scale deposition and sand-related issues. Motor shrouds can prevent overheating and regular well cleaning helps keep pump flow passages clear further reducing ESP failures.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the corresponding author

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