INSIGHTS INTO CAUSES OF FAILURE OF SUBMERSIBLE PUMP, MARITIME ACCIDENTS AND ONBOARD REGULATIONS

Supported by tetfund
TERTIARY EDUCATION TRUST FUND

[1]Olanrewaju Afolabi Layiwola*, Thaddeus Chidiebere Nwaoha, Jasper Ahamuefula Agbakwuru and [2]Ezenwa Alfred Ogbonnaya

[1]Department of Marine Engineering, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria
[2]Department of Marine Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
Email: lanrelayiwola@yahoo.com

Received: September 5, 2025, Accepted: November 28, 2025

Abstract

In this paper, an analysis of various components of ship submersible pumps such as impeller, motor, mechanical seals, thrust bearing, electrical cable, housing, shaft, pressure sensing instrument and variable speed drive are carried out. Marine submersible pump related accidents and various causes of failure of the submersible pump mechanical seals are discussed, including pump vibration, dry running of the pump, temperature (higher), unsuitable start up procedures and wear and tear in maritime environment. Also, regulations governing safety of machineries onboard vessels are discussed.

Keywords: Ship Submersible Pump, Marine Accident, Regulations, Components, Failure, Mechanical Seal

1. Introduction

The flow rate of fluid from bilge well or cargo holds or submerged compartment of a vessel is greatly increased or maintained using electrical submersible / semi-submersible pumps. These pumps are mainly positioned vertically, and the pump is divided into various sections, the pump casing section, the motor section and the seal section. The recurring failure of submersible pump and cost of installation of replacement pumping system is very high; these issues have resulted in the development of highly reliable pump with longer running lifespan. The research of the reliability of submersible pump section was done at Texas A & M Turbomachinery Laboratory; it focuses on the modeling and testing of the submersible pump by operating it on a multiphase fluid in determining the mechanical seal reliability. The seal to be tested is subjected to large amplitude of vibrations to see the static performance of the system process and the thrust bearing lubrication process. The failure of the submersible pump seal was as a result of the erosion of the diffuser and impeller blade mainly caused by the presence of gas and sand in the fluid to by pumped (Abhay et al., 2018).

The use of submersible pumps is vital for the smooth operation of the oil and gas industry and in the maritime industry. Submersible pump can handle large volumes of fluid with wide range of application under severe operating conditions. Submersible pump suffers numerous failures over the years, the failure mostly associated with submersible pump are either mechanical, electrical, environmental and operational as the case maybe. These failures are as a result of the assembling in the down hole. Understanding the causes and modes of failures of submersible pump will help in controlling the rate of failure of the pump thereby cutting down the cost of repair/replacement of the pump. It will also help in improving the safety of its operation and also the lifespan of the pump. In order to minimize the rate of failure of submersible pump, the selection of material for its design is necessary to reduce the effect of corrosion and the most active aspect of submersible pump failure was as a result of electrical failures (Sherif et al., 2021).

2. Overview of Submersible Pump Onboard a Ship

Submersible pump on semi-submersible ship is powered by electric supply from a transformer or a switch board. The system is made up of a centrifugal pump, control mechanism, cable, seal, gas separator and a motor that drives the pump as shown in Figure1. The fluid flows from the well through the strainer, the motor and passing through the gas separator and up to the pump before discharging. It provides a cost-effective and successful ways of lifting large volume of fluids at a higher flow rate during operation. Submersible pump is resistant to corrosion and can operates in a very harsh environment and have a wider flow rate. The system is sensitive to gas and sand contained in the fluid to be pumped, which can cause serious damage to the pump (Baker Hughes Centrilift, 2008; Canadian Oilwell System Company, 2010).

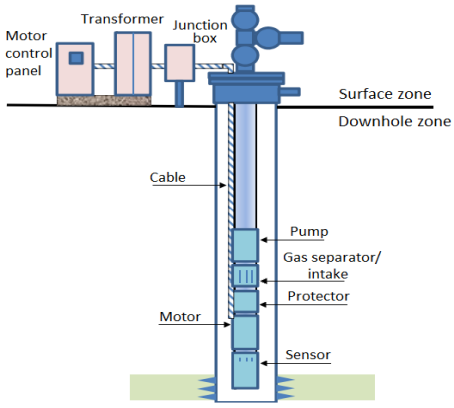

Figure 1: Electrical submersible pump (Fonseca et al., 2019)

Submersible pump plays a vital role in the safety of maritime industry for floating platform. This pump is also used onboard ship in evacuating ingressed water onboard and de-ballasting flooded tanks. When submersible pump onboard a vessel fails, it may result to loss of life, loss of ship resulting in wreck that is hazardous to navigation and causes environmental pollution. The timely identification of the fault and maintenance done on it will greatly improve the

well-being of the ship, crew and ultimately the economy of the company. The fault diagnosis of the submersible pump system is very prevalent in various countries in meeting the requirements of various regulatory agencies. This measure will also help in preventing the marine environment from ecological breakdown. One of the fault diagnosis techniques used for fault finding is the mechanical variation model. The model uses different types of sensors to help monitor the variation signal during the operation of the pump. This signal will then be analyzed to diagnose the fault of the submersible pump. Also, neutral network can be used in diagnosing the fault of the submersible pump, but it will require large data base in analyzing the pump fault. In order to reduce the use of large data base as in neutral network and the numbers of sensors needed in the analysis, the use of algorithms designed to diagnose the fault of submersible pump was used in this research. The algorithms were based on the extraction of feature data and this data is simulated to achieve the desired objectives of the research (Zhang et al., 2017).

3. Description of Submersible Pump Onboard Ship

There are various types of pumps used in the maritime industries and they are made for different types of operation. These pumps must meet and comply with the technical standard for design, construction and maintenance set by the relevant classification societies. These pumps are basically categorized into two (2) broad types and they are as follows.

- Positive Displacement Pumps (e.g. Gear Pumps, Screw Pumps, Reciprocating Pumps etc).
- Non-Positive Displacement Pumps (e.g. Centrifugal Pumps of which are single or multi-stage), Dynamic Pressure or Roto-Dynamic Pumps (e.g. Submersible Pump, Axial flow Pump, Centrifugal-Axial flow pump etc).

These pumps are designed to handle different types of fluid depending on the type of materials being used for its manufacture. Most of the marine pump are self-priming and are positioned vertically with the motor at the top position (KSB, 2020). The marine bilge pump can either be centrifugal, diaphragm, reciprocating or flexible impeller pump. The centrifugal submersible pumps are used in both large and small vessels for the discharge of accumulated water in the bilge tank overboard. The submersible pump used onboard can be a life saver in case of flooding by waves especially if the hull of the ship is holed. The pump is capable of removing the water effectively to allow for the repair of the damaged hull section of the ship to prevent the ship from sinking (Caver pump, 2020). Submersible pumps used on cargo vessels are centrifugal pump driven by hydraulic motor for efficient operation as shown in Figure 2. This submersible pump is used to pump different types of liquid cargo without regards to the liquid viscous nature. This submersible pump is made up of stainless steel with smooth surface for easy cleaning. The pump is positioned vertically and it is of a single stage design. The pump seal can be monitored by removing the cofferdam from the plate top of the pump during the inspection process of the seal for damage (Framo, 2022a).

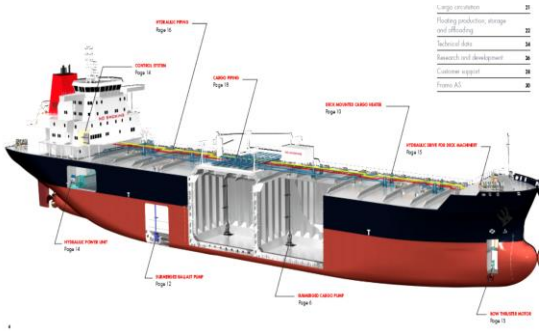

Figure 2: Submersible pump in cargo vessel (Framo, 2022a)

The types of submersible pumps found in ocean going vessel depends on the types and size of the vessel. Some of these pumps are as follows:

- Submerged tank cleaning pump
- Submerged ballast pumps
- Submerged cargo pumps

These submersible pumps are powered by either hydraulic or electric units depending on the manufacturer and they are operated from a remote position in the wheelhouse and /or cargo control room as shown in Figure 3. This type of submersible pump controls allows for quick loading and unloading of bulk liquid cargo. It improves the performance of the cargo handling process and also enhance efficient and safe discharge of liquid cargo from the vessel. This pump aids the ballasting and de-ballasting process of the vessel for her effective stability (Framo, 2022b).

Figure 3: Hydraulic power unit (Framo, 2022a)

4. Components of Submersible Pump

Submersible pump system has also proven to be very efficient in the maritime industry for the transfer of liquid cargo and de-ballasting process. The pump is designed to operate in a vertical position. They are single or multistage pumps. Some of the major components of the submersible pump are impeller, motor, seal, thrust bearing, cable, housing, shaft, pressure sensing instrument, and variable speed drive.

Impeller: The impeller is the solid rotating component of a pump in the form of curved blades arranged on a central hub that transfer energy from the motor to the fluid causing the fluid to flow and gather pressure. It is shown in Figure 4. The function of the pump is to produce the needed centrifugal forces after it has been subjected to pressure, making the impeller to rotate at a higher speed for the movement of the fluid up through the discharge pipe. In the process, the

kinetic energy in the diffuser is lost in other to convert this rotational energy to pressure force (Gabor, 2009).

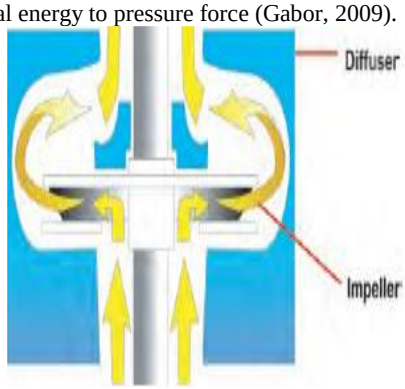

Figure 4: Submersible pump impeller (Gabor, 2009)

Motor: The types of motor used in the design of some submersible pumps are of two-pole three phase induction type as shown in Figure 5. The process of operation of this motor is by electromagnetic induction in which the magnetic field is created in the stator and one of the coils is contained at each phase on the standing part of the motor. The rotation of the motor produces a field which is caused by the change of direction of the alternating current being produce. The speed of the motor depends greatly on the frequency of the alternating current and also the number of stator poles. A shaft is attached to the motor which serves as the rotor. The rotor is design as a squirrel cage of copper bar which is not coupled to the source of power (Butlin,1991).

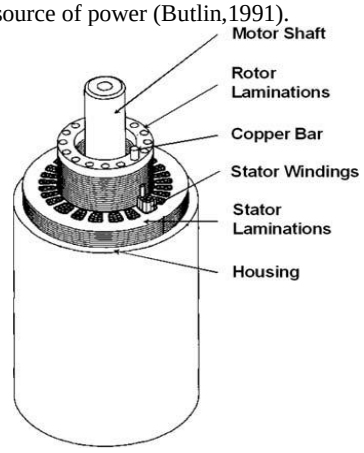

Figure 5: Submersible pump motor (Gabor, 2009)

Seal: The seal installed between the motor and the pump is referred to as a protector, this seal protects the motor from water (fluid) ingress. It is mounted on motor shaft and comprises of stationary ring and rotating rings on which rubber bellow and springs are mounted. It is prevented from playing around on the shaft by a circlip. The ingress of this fluid into the motor section will be dangerous for the continuous running of the submersible pump. The motor of a submersible pump is filled with electric strength oil and when the motor is operating at a high temperature, the housing (casing) of the pump will burst if the housing is completely sealed. This is as a result of the development of pressure inside the housing due to the oil expansion. In this way, the only components having protective seal are the pump and the motor sections as shown in Figure 6 (Swatek, 1997).

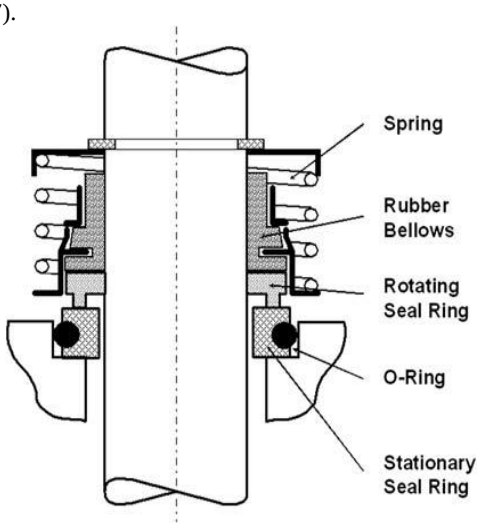

Figure 6: Submersible pump seal arrangement (Gabor, 2009)

Thrust bearing: The axial forces being developed during the operation of the submersible pump are absorbed by the thrust bearing. It comprises of the finely finished circular ring called thrust runner and the thrust shoes on either sides. The thrust bearing is installed in the units containing the seal (protector), it is used to reduce the bulk of the thrust forces that is developed from the operation of the motor. Submersible pump uses pad-type plane bearings because of the reduced heat produced during its operation. The bearing supports higher loads and can operate with lubricating oil having contaminants in it. The load carrying capacity of this bearing relies greatly on the fluid film. The fluid film protects the metal-to-metal contact of the stationary and moving parts of the thrust bearing as shown in Figure 7 (Zeidan & Jain, 2000).

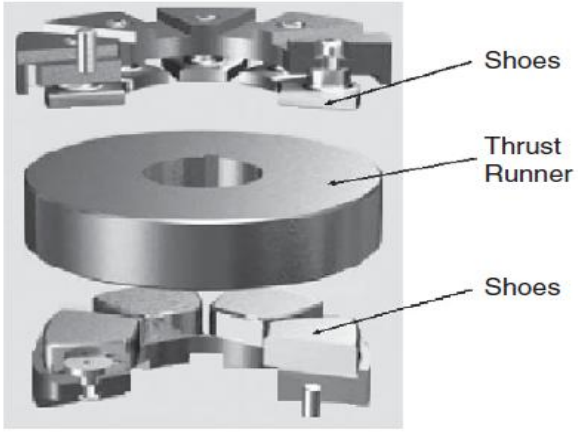

Figure 7: Submersible pump thrust bearing (Gabor, 2009)

Cable: Submersible pump cable is of three phases, it is used for the transmission of electricity to the motor, from the power source to the motor connection as shown in Figure 8. The submersible pump operates under a very severe

environment and the following requirements needs to be met for the safe operation of the pump under the API regulations:

- The wire diameter must be small to allow for free passage
- Their deflective properties must be maintained under severe environmental conditions (e.g. temperature, fluid & gas)
- Protected against damage
- Must be insulated to endure high temperature
- Must be resistant to oil/water
- Does not allow the migration of gases into the cable (API, 1993).

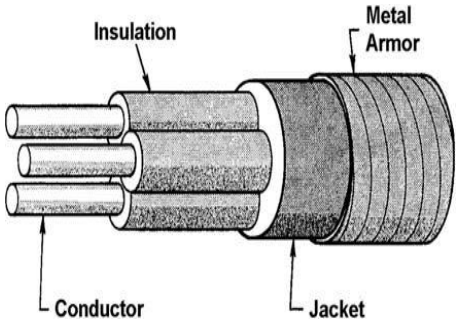

Figure 8: Submersible pump cable (Gabor, 2009)

Housing: The various component of submersible pump is housed to prevent the fluid from getting access to the vital parts of the pump as shown in Figure 9. The housing is made of alloy steel grade material, the surface on the outside of housing is coated to protect it from corroding due to the corrosive nature of the fluid that is been pumped or the type of environment in which the pump is been used.

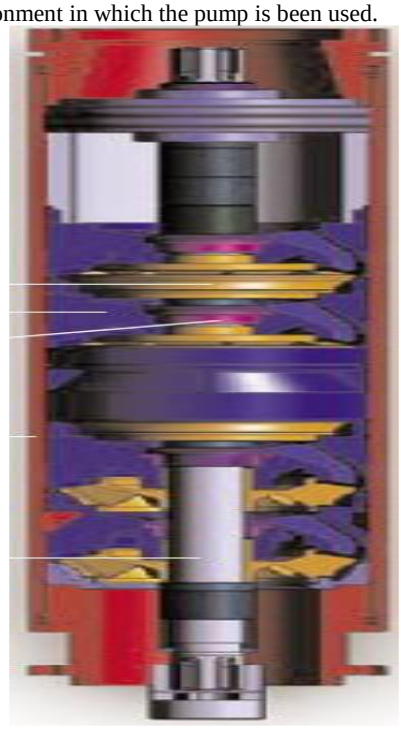
Figure 9: Submersible pump housing unit (Canadian Advanced Incorporated, 2016)

Shaft: The shaft of the submersible pump is made up of finely finished Monel k-500 material. This gives the shaft the needed strength to maintain the high torque generated from the motor as shown in Figure 10 (Canadian Advanced Incorporated, 2016).

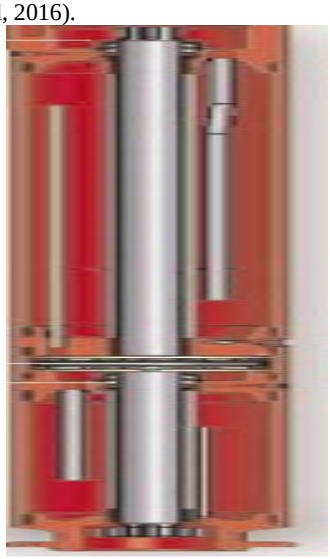
Figure 10: Submersible pump shaft and thrust bearing arrangement (Canadian Advanced Incorporated, 2016)

Pressure sensing instrument: It is an instrument used to read out the operating temperature and pressure of the submersible pump during running. The pressure sensing instrument is made up of two components which are transducer/sensing unit at the down-hole and the surface readout unit.

The variable speed drive: It is a switchboard that controls the speed of the submersible pump motor, which functions to vary the capacity of the pump. It prevents the component from power transient and provides capacity for soft-start of the pump motor (Powers, 2020).

5. Ship Accidents Caused by Submersible Pump Failure

The ballast system of ships and semi-submersible vessels are maintained and stabilized by submersible pump which controls the vessel draft and trim. This pump controls the amount and rate of water ingress into watertight and engine compartment as well as cargo holds. Some of the accidents caused by failure of semi-submersible pump onboard vessels are as follows:

Ocean Ranger: It is a semi-submersible offshore mobile rig owned by ocean drilling exploration company. The unit was built by Mitsubishi Heavy Industry and this unit operated at 1500ft beneath water and 25000ft deep of drilling. The length, width and height of the vessel are 122m, 80m and 41m respectively. This unit capsized during drilling operation at an oil well in Canadian water in 1982 of which all 84 crew members on-board the vessel died. The vessel sank as a result of wave impact on the hull where the ballast control room was located. This caused two portholes on the hull structure to fail, compromising the control panel in the control room resulting in the malfunctioning of the valve (opening). This effect caused the valve to open allowing ingress of water into the structure without any means of

closing the valve due to damage on the pump control panel (Vinnem, 2000; Sobena, 2007).

Petrobras P-36: It was a Floating, Production Storage and Offloading (FPSO) platform operating in the waters of Brazil, about 125km off the coast. The vessel was designed in Italy as a semi-submersible rig, which was converted later to FPSO from 1997 to 1999 when she was fully modified. The vessel had a capacity of up to 1360m for deep water operation with parameters of 112.8m, 77m and 119.1m for her length, width and height respectively. This vessel exploded on March 20th, 2021 abaft of the starboard side which made her sink. Out of the 175 crew members that were on-board the vessel, 11 of them died. This explosion affected the fire pipe which was connected to the valve of the sea chest. The semi-submersible pump was faulty, so was not available to reduce the rate of water ingress to the various watertight compartments (Sobena, 2007).

BP Thunder Horse: This platform was a semi-submersible rig unit operated by BP and Exxon Mobil. This vessel was the largest deep-water vessel operating in the Gulf of Mexico and with 250,000 barrels' capacity of oil, and 200mmscfd of gas per day. The vessel was found to be listing at 20^{O} after the impact of Hurricane Denis. With a 110.8m, 104.96 and 57.5m size for her length, width and height respectively. The Hurricane affected the hydraulic valve control system of the semi-submersible pump, some wire cables that were also damaged around the hull and also cracks on the underwater pipeline. This made the operation of the semi-submersible pump difficult in returning the vessel to stability (SINTEF, 2011; Lyall, 2010).

Ocean Way: The fishing trawler went down about 20 miles off Lerwick, UK on 3rd March, 2017 with all five crew members surviving. The vessel suffered "uncontrolled flooding" while trying to bring her net up. During trawling, one of the trawl doors- which are objects similar to large metal rudders that keep the net open- struck the hull. The impact was great enough to create a breach estimated at between 6-17 square inches in size letting water flow into an airtight compartment. The crew battled to save the vessel using portable submersible pump. The situation continued to deteriorate with a pump breaking down. With no prospect of recovering the situation, it was decided that all crew members should abandon ship and were taken aboard the lifeboat. The accident resulted in inevitable loss through rapid down flooding of the vessel (MacLennan, 2018).

Swaraj Dweep: On 2 August 2018, the mainland-Island passenger vessel with 343 Chennai passengers onboard developed a hole in the hull after she sailed from Campbell Bay via Nancowry Island for Chennai and sea water started gushing in. She sought assistance from Indian Coast Guard's MRCC. Coast Guard ship ICGS Aruna Asif Ali swiftly sailed from Kamorta to assist the distressed vessel and the vessel was able to be de-flooded using submersible and diesel driven pumps (Thehindu, 2018).

Raj Ayushi: On August 3 2022, the Indian Coast Guard District Headquarters at Okha received information regarding uncontrolled flooding onboard fishing boat "Raj Ayushi" in Gujarat Sea nearly 10NM off Okha port. On getting there, the boat was partially submerged due to heavy flooding and all the five (5) crew members were rescued. Using a submersible pump, the Coast Guard personnel managed to control the flooding and brought the boat to Okha (Deshgujarat, 2022).

USS LING: About September 2019, USS LING World War II-era submarine berthed in the Hackensack River and used as a post war era Naval Museum started taking in water. For a year and half, as much as 14 feet of murky river water filled the hull of the 312 foot long, 1,500-tonne vessel after vandals flooded the boat. Water filled every corner of the submarine, damaging her. Gallon by gallon, with a submersible pump, a group of veterans and military enthusiasts pumped out the water (Kaulessar, 2019).

SAPUTI: On 21 February 2016, the Canadian flagged fishing vessel having 30 crew onboard was fishing turbot in the Davis Strait, 167 nautical miles east-northeast of Resolution Island, Nunavut, and 220NM west-southwest of Nuuk, Greenland. At 1935 hours Atlantic Standard Time, the vessel struck a piece of ice and was holed in the shell plating on the Starboard side at the forward end of the cargo hold. The vessel was flooded and developed a severe list (25 degrees) to port side. HDMS Knud Rasmussen arrived the SAPUTI with 2 gasoline powered submersible pumps and 2 electric powered submersible pumps. With these 4 pumps running, the water level receded. Some of the vessel's equipment were over boarded and the vessel eventually sailed to Nuuk on 24 February at 0023 hours (TSB, 2016).

PECOS PETERS: About February 2011, PECOS PETERS, "ex" PECOS RIVERS, a Nigerian registered platform support vessel owned by HighTide Marine had a previously patched side of the hull failed and the holed hull started to take-in water around Addax field offshore Nigeria. Her submersible pump was deployed and the sea water ingress into the vessel was contained for the vessel to return to base for proper welding work to be carried out.

ZION VOYAGE: A 1982 built, 1026 GT Nigerian registered Offshore Tug / Supply Vessel. In 2018, the vessel sank offshore Nigeria due to water ingress into the ship. At the time of the incident, the vessel did not have functional submersible pump.

CAVALCADE: Cavalcade, a 476 GT offshore Tug/Supply vessel was built in 1977. About June 2022 when she sank off the coast of Brass, not far from NEST Oil rig, she was working for Conoil. She was taking in water and subsequently sank due to non-availability of submersible pump.

OMAMBALA RIVER: She is a 257 GT crew boat built in the year 2000. Around 2005 while working in EKPE Oil field, she developed a hole on the hull and started to take in water and was listing. She was then rescued through use of submersible pump to pump out the sea water already taken in and a cement patch used temporarily to stop the water coming in. As at that time, she was under the Management of Fymak Marine.

6. Causes of Failures of Submersible Pump

Failure of impeller, motor, seal, thrust bearing, cable, housing, shaft, pressure sensing instrument and variable speed drive causes submersible pump failure. The seal in a submersible pump protects the pump motor from the ingress of fluid. For low pH water of acids or higher salt level can cause corrosion of the internal structure of the motor and bearings. Submersible pump uses mechanical seal which is manufactured with a carbon/ceramic materials or better still with silicon/carbide materials. The latter is harder and suitable for transmitting fluid with sandy particles (Sgritta, 2001). The failure of submersible pump seal leads to a condition where by the water tight integrity of the housing of the motor and the pump will be compromised. The housing of a submersible pump motor is usually occupied by oil. When it is damaged, there will be water ingress into the various section that will destroy the system vital components as well as corroding the bearings. The major factors that cause the failure of submersible pump seal are pump vibration, bent shaft, dry running of the pump, temperature (higher), unsuitable start up procedures and wear and tear.

Failure of the submersible pump seal cannot be totally prevented due to the harsh operating conditions of the system in which they operate but can be mitigated. But the use of the seal failure detector attached to the controller box of the pump is important. The failure detector uses probe sensors in detecting and monitoring the progress of the seal to failure during its operating period. The sensor gives the data and when maintenance will be needed on the pump (Sunbelt Power Controls, 2015). Also, regular testing of the insulation resistant (I.R) of the pump cable and coil using megger tester is advisable to monitor the trend in the condition. If the insulation resistant values (Mega Ohms) continue to drop for any of the pump, it shows deterioration (gradual breakdown of the seal components, e.g. “O rings”) and this will indicate moisture and/or water ingress into the electrical side of the pump which will ultimately cause breakdown of the coil and pump. The major constituent of submersible pump water proofing is the seal of the system. The pump then fails when the seal begins to leak. The failure of the seal affects the smooth running of the pump (Vogel, 2021).

Submersible pump seal can also fail when the pump is running dry without fluid. The pump will then be subjected to high friction and heat being generated from the rotating parts of the pump (metal to metal contact) because there is no fluid for the cooling/lubrication of the system. This will result in the failure of the pump because the seal is running dry. When the material used in the design of the submersible pump seal is incompatible with the fluid in use in the pumping process, this can cause attack of the seal material chemically and also the gaskets of the diffusers, pump casing and impellers. This can also result in the deterioration of the internal components and subsequent failure of the submersible pump. Operating submersible pump in harsh environment (temperature and pressure) will also cause the elastomers to melt or swelling of the seal and this will ultimately result in leaking of the seal section of the pump. The leaking of the pumping fluid into the motor section will damage the submersible pump motor and subsequent failure of the pump. Incorrect installation of the pump seal will equally cause the seal to wear and be damaged since most seal is designed to move with the shaft. When this movement is restricted by the incorrect seal lifting, the seal will wear out. When the shaft of a submersible pump has excessive clearance, the seal will be the one to first absorb the forces from the movement of the shaft instead of the bearing. This will cause the seal to tear due to the excessive force from the shaft movement (Hooton, 2021).

Submersible pump can also fail after improper replacement of seal when it is damaged. This can occur when the shaft outside diameter has been reduced due to wear over the years, this new seal to be replaced will not fit well on the shaft. This will cause the leaking of the pumping fluid into the motor section of the pump, thereby causing the pump to fail due to damaged motor windings. The ingress of solid particles in the fluid to be pumped will cause these solid particles to settle on the surface of the seal. With time, these solid particles will cause the seal to be wearing out as the pumping process continues. Wearing of the seal will results to the leaking of the seal section of the pump which will cause the ingress of fluid into the motor section of the pump and subsequent failure of the pump (Hooton, 2021). The logical relationship of these failures can be established and investigated using safety and uncertainty treatment model deployed in the works of Nwaoha et. al. (2016a, 2016b)

7. Regulations Governing Safety of Machineries Onboard Vessel

This is built upon the International Standard Organization (ISO-14224) and the American Petroleum Institute (API) recommended practice (RP IISI). The failure analysis guideline, components parts and the tear down limit of the submersible pump are given in the API PR IISI, these are also pointed out in the ISO-14224 guidelines. The guidelines review the practices of past data collected from industry, type of analysis to be done of the data and difficulties relating to such data are given in the guidelines. Also included in the guidelines are maintenance to be carried out on the equipment and the operational evaluation of the system in predicting the future rate of failure of the submersible pump (Alhanati et al., 2001). The regulation regarding the requirements for machinery and electrical equipment onboard vessels states that ship should be constructed to make sure that services that are necessary for the ship safety, crew members and passengers as the case may be, cargo and environmental factors are sustained under several conditions of emergency. The requirement for newly built ship should be designed in a way that it has to be environmentally friendly, safe in operation and the damaged conditions for the vessel lifespan should be specified. The hull of the vessel should have sufficient strength, watertight integrity and with good stability to mitigate the risk of ship loss or environmental pollution. This is as a result of failure of the hull structure, breakdown and flooding of the vessel due to loss of her watertight integrity (IMO, 2019).

8. Conclusion

The importance of adhering to the safety standard and regulation guidelines for machinery and equipment are very

necessary for good maintenance practice onboard a vessel. The need for equipment e.g. (submersible pump) failure needs to be addressed critically especially as it affects the ballast systems, safety and stability of the ship, most especially when the water tight integrity of the underwater section has been compromised. Cases of pump failures are necessarily mentioned as a learning curve to prompt the crew on proactive measures as per what to do in case of this critical item failure onboard and how to reduce the impact on the vessel during emergency. In this study, we described various components of ship submersible and maritime accidents caused by failure of the submersible pump. The major factors that caused failure of the seal of submersible pump were also provided.

REFERENCES

Abhay, P.; Adolfo, D.; Yi, C.; Daniel, S.; Chang-rui, B.; Yi-ming, C. & Gerald, M. (2018) "Mechanical Reliability of Electrical Submersible Pumps", China Journal of Turbomachinery, 60, Issue 5, pp. 69-77.

Alhanati, F. J. S.; Solanki, S. C. & Zahacy, T. A. (2001), "ESP Failure: Can We Talk the Same Language?", Society of Petroleum Engineers Workshop, April 25-27, Houston, USA, pp. 1-11.

API (1993), "Recommended Practice for Application of Electric Submersible Cable Systems*"* PRIISS (1st Ed), American Petroleum Institute.
Baker Hughes Centrilift (2008), "Submersible Pump Handbook", Eight Edition Version 2, Claremoves, Oklahoma. p.10.

Butlin, D. M. (1991), "The Effect of Motor Ship on Submersible Pump Performance", Electrical Submersible Pump, Workshop, April 29-May 1, Houston, Texas, pp. 72.

Canadian Advanced Incorporated (2016), "Electrical Submersible Pumps", www.cai-esp.com/products/electric-submersible-pumps/ Accessed on 22nd November, 2025.

Canadian Oilwell System Company Ltd (2010), "Basic Artificial Lift", www.coscoesp.com/esp/basic%20artificial%20lift%20tech%20paper/basic%20artificial%20lift.pdf. Accessed on 12th January, 2025.

Carver Pump (2020), "Marine Bilge Pumps: The Ultimate Guide for Ships", www.carverpump.com/marine-bilge-pumps-the-ultimate-guide-for-ships/ Accessed on 2nd February. 2025.

Deshgujarat (2022), "Indian Coast Guard Rescues Five Fishermen During Midnight Operation Off Okha Coast", https://deshgujarat.com/2022/08/03/indian-coast-guard-rescues-five-fishermen-during-midnight-operation-off-okha-coast/ Accessed on 22nd November, 2025.

Fonseca, D.; Salazar, A.; Goncalves, T. & Villarreal, E. (2019), "Electrical Modelling of An Electrical Submersible Pump System Three Phase Power Cable used in Power Line Communication", PrzegladElekrotechniczny, Vol. 10, Issue 4, pp. 21-26.

FRAMO (2022a), "Tankers with FRAMO Cargo Pumping System", www.framo.com/cargo-pumping-systems/cargo-pumping/Types-of-tankers/ Accessed on 10th April, 2025.

FRAMO (2022b), "The FRAMO Submerged Cargo Pump", www.framo.com/cargo-pumping-system/cargo-pumping/submerged-cargo-pumping/ Accessed on 17th March, 2025.

Gabor, T. (2009), "Electrical Submersible Pumps Manual: Design Operation and Maintenance", Gulf Professional Publishing.

Hooton, S. (2021), "8 Reasons for Mechanical Seal Failure", https://www.northridgepumps.com/article-332_8-reasons-for-mechanical-seal-failure Accessed on 22nd November, 2025.
IMO (2019), "International Convention for the Safety of Life at Sea (SOLAS), 1974", www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx. Accessed on 22nd November, 2025.

Kaulessar, R. (2019), "Group of Maritime Enthusiasts Take on Major Task of Saving Hackensack Submarine USS Ling", https://www.northjersey.com/story/news/bergen/hackensack/2019/09/14/uss-ling-in-hackensack-nj-group-of-maritime-enthusiasts-take-on-major-task-of-saving-submarine/2311898001/ Accessed on 2nd September, 2024.

KSB (2020), "Marine Pump", https://www.ksb.com/en-global/centrifugal-pump-lexicon/article/marine-pump-1118466 Accessed on 3rd March, 2024.

Lyall, S. (2010), "In BP's record a history of boldness and costly blunders" New York Times. www.nytimes.com/2010/07/13/business/energy-environment/13bprisk.html Accessed on 23rd November, 2025.

MacLennan, S. (2018), "Ocean Way trawler probe finds vessel breached regulations", https://www.pressandjournal.co.uk/fp/news/highlands-islands/1481866/ocean-way-trawler-probe-finds-vessel-breached-regulations/ Accessed on 22nd November, 2025.
Nwaoha, T. C. and John, A. (2016), "Some Insights in Novel Risk Modelling of the LNG Carrier Maintenance Operations" *Journal of Marine Science and Application, Vol. 15, Issue 2, pp. 144-156.*

Nwaoha, T. C. John, A. and Agbakwuru, J. (2016), "LNG Carriers Safety: A Research Perspective", *International Journal of Science and Technology, Vol. 5, No. 7, pp. 324-338.*

Powers, W. J. (2020), "Petroleum Engineering Handbook: Electrical Submersible Pumps Chapter 7",

https://pdfcoffee.com/electric-submersible-pumps-5-pdf-free.html Accessed on 4th June, 2024.

Sgritta, T. (2001), "How to Avoid Submersible Pump Problems in Motors" www.wwdmag.com/automation/motors-submersible/article/10917575/how-to-avoid-submersible-pump-in-motors Accessed on 8th September, 2024.

Sherif, F.; Abdelaziz, K.; Enamul, H. M. & Hashim, N. (2021), "Rigorous Review of Electrical Submersible Pump Failure Mechanisms and their Mitigation Measures", *Journal of Petroleum Exploration and Production Technology*, Vol. 11, pp. 3799–3814.

SINTEF (2011). "Deepwater Horizon-ulykken: Årsaker, Lærepunkter og Tiltak for Norsk Sokkel", https://www.sintef.no/prosjekter/2011/deepwater-horizon-ulykken-arsaker-larepunkter-og-t/ Accessed on 8th September, 2024.

Sobena (2007), "Marine Systems and Ocean Technology", https://sobena.org.br/noticia/periodico-sobena-marine-systems-and-ocean-technology-msot/ Accessed on 6th September, 2025.

Sunbelt Power Controls (2015), "Seal Failure Detection in Submersible Pumps", www.sunbeltpowercontrols.com/seal-failure-detection-in-submersiblepumps/#:~:text=seal%20failure%20is%20a20conditions,is%20normally%20filled%20with%20oil Accessed on 6th May, 2025.

Swatek, M. A. (1997), "Seal Section Functions and Application Considerations", ESP Workshop, April 30-May 2, Houston, Texas, USA.

Thehindu (2018), "343 Personnel from Flooded Passenger Ship Rescued" https://www.thehindu.com/news/national/343-personnel-from-flooded-passenger-ship-rescued/article24582971.ece Accessed on 5th October, 2025.

TSB (2016), "Marine Transportation Safety Investigation Report M16C0016: Striking of Ice and Subsequent Flooding on Fishing Vessel Saputi", https://www.tsb.gc.ca/eng/rapports-reports/marine/2016/m16c0016/m16c0016.html Accessed on 22nd November, 2025.

Vinnem, J. E. (2000), "Operational Safety of FPSO's: Initial Summary Report", Offshore Technology Report, Health and Safety Executives. https://dvikan.no/ntnu-studentserver/reports/Operational%20safety%20of%20FPSOs.pdf Accessed on 18th December, 2024.

Vogel, E. (2021), "Causes & Solutions for Leaking Pump Mechanical Seals", https://www.pumpsandsystems.com/causes-solutions-leaking-pump-mechanical-seals Accessed on 24th August, 2024.

Zeidan, F.Y. & Jain, D. (2000), "Application of Hydrodynamic Thrust Bearings in Submersible Pumps", ESP workshop, April 26-28, Houston, Texas, USA.

Zhang, Panlong; Chen, Tingkai; Wang, Guochao & Peng, Changzheng (2017), "Ocean Economy and Faults Diagnosis of Electric Submersible Pump Applied in Floating Platform". *International Journal of e-Navigation and Maritime Economy*, Vol. 6, pp. 37-43.