

Root Cause Analysis and Solutions for the Decline in Freshwater Generator Production: A Case Study of MV Top Diligence

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Abstract

A freshwater generator is a crucial system in ship operations that produces fresh water from seawater via vacuum distillation. This research aims to identify the causes of decreased fresh water production in fresh water generator and analyze the effectiveness of corrective measures undertaken. The research employed a case study method with a qualitative approach conducted on MV. Top Diligence during the period from October 2024 to August 2025. Data collection was conducted through participatory observation, in-depth interviews with the Third Engineer and related crew members, and a documentation study of the daily record book, the planned maintenance system, and the instruction manual. Data analysis used the root cause analysis method with the 5 Whys technique and a fishbone diagram. Research findings indicate that production decrease from 20-23 tons/day to 13.8 tons/day (30.8% reduction) was caused by three main factors: seal damage on evaporator plate which reduced system vacuum from 0.9 bar to 0.6-0.7 bar, fouling or scale accumulation of 2-5 mm thickness that impeded heat transfer, and ejector pump pressure reduction from 3-3.5 bar to 1.5 bar. Corrective measures, including mechanical scale removal, gasket replacement, and ejector pump maintenance, proved effective, resulting in production recovery to an average of 20.8 tons/day (46% increase). This research concludes that preventive maintenance with intervals adjusted to operational conditions (3-4 months) and strict monitoring of critical parameters are essential to maintaining optimal performance of fresh water generators. The research findings provide practical contributions in the form of recommendations for planned maintenance system revision and early warning system implementation to prevent performance degradation in the future.

Keywords: Fresh Water Generator; Ship Maintenance; Root Cause Analysis; Preventive Maintenance

Abstrak

freshwater generator merupakan sistem penting dalam operasi kapal yang menghasilkan air tawar dari air laut melalui distilasi vakum. Penelitian ini bertujuan untuk mengidentifikasi penyebab penurunan produksi air tawar pada freshwater generator dan menganalisis efektivitas tindakan korektif yang dilakukan. Penelitian ini menggunakan metode studi kasus dengan pendekatan kualitatif yang dilakukan pada MV. Top Diligence selama periode Oktober 2024 hingga Agustus 2025. Pengumpulan data dilakukan melalui observasi partisipatif, wawancara mendalam dengan Third Engineer dan anggota kru terkait, serta studi dokumentasi buku catatan harian, sistem perawatan terencana, dan buku petunjuk. Analisis data menggunakan metode root cause analysis dengan teknik 5 Why dan diagram fishbone. Hasil penelitian menunjukkan bahwa penurunan produksi dari 20-23 ton/hari menjadi 13,8 ton/hari (penurunan 30,8%) disebabkan oleh tiga faktor utama: kerusakan segel pada pelat evaporator yang mengurangi vakum sistem dari 0,9 bar menjadi 0,6-0,7 bar, penumpukan kerak atau endapan setebal 2-5 mm yang menghambat perpindahan panas, dan penurunan tekanan pompa ejektor dari 3-3,5 bar menjadi 1,5 bar. Tindakan korektif, termasuk pembersihan kerak secara mekanis, penggantian gasket, dan perawatan pompa ejektor, terbukti efektif, menghasilkan pemulihan produksi rata-rata menjadi 20,8 ton/hari (peningkatan 46%). Penelitian ini menyimpulkan bahwa perawatan pencegahan dengan interval yang disesuaikan dengan kondisi operasional (3-4 bulan) dan pemantauan ketat terhadap parameter kritis sangat penting untuk mempertahankan kinerja optimal freshwater generator. Hasil penelitian memberikan kontribusi praktis berupa rekomendasi untuk revisi sistem perawatan terencana dan implementasi sistem peringatan dini untuk mencegah penurunan kinerja di masa mendatang.

Kata Kunci: *Freshwater Generator; Perawatan Kapal; Root Cause Analysis; Perawatan Pencegahan*

INTRODUCTION

Fresh water is a vital requirement in ship operations, both for crew needs such as drinking, cooking, and sanitation, as well as for ship machinery systems such as main engine cooling. Ships sailing for extended periods require large quantities of fresh water, which, if entirely carried from shore, would reduce cargo capacity and significantly increase operational costs (Amrullah et al., 2024). Therefore, modern ships, particularly those operating in open seas (ocean-going), are generally equipped with fresh water generation systems or fresh water generators that can process seawater into fresh water through a distillation process. A freshwater generator is auxiliary machinery that produces fresh water from seawater via vacuum distillation (Budi, 2013). This system utilizes the principle of reduced atmospheric pressure inside a vessel to lower the boiling point of water, enabling seawater to evaporate at a lower temperature, typically around 60°C (Suparwo, 2019). According to Jackson and Morton (2003), the basic principle of vacuum distillation is to exploit the relationship between pressure and the boiling point of liquids: the lower the pressure in the system, the lower the temperature required to evaporate water. The heat used for the evaporation process generally comes from utilizing waste heat from the main engine cooling system, so this system also contributes to the ship's overall energy efficiency (Shimizu, 2021).

The heat transfer process in a freshwater generator involves heat transfer mechanisms through a heat exchanger. Abou Elmaaty et al. (2017) state that heat exchanger efficiency is highly dependent on its ability to transfer high heat rates with low pumping power and minimum operational costs. Clean heat exchanger surfaces, free of scale and fouling, are key to maintaining optimal heat transfer efficiency. The reliability of a freshwater generator is crucial for the continuity of ship operations. Decreased fresh water production capacity can have serious impacts on voyage smoothness, especially on long-distance routes where access to shore-based refilling is very limited. Various factors can cause decreased performance of the freshwater generator, including reduced vacuum in the system, fouling or scale accumulation on evaporator plates, leaks in the piping system, and decreased ejector pump efficiency (Sirman & Syahrinal, 2023). Optimal vacuum conditions are critical for determining evaporation process efficiency and the amount of fresh water produced (Narto, 2019). Suparwo (2001) explains that there are two main types of freshwater generators based on their operating pressure: the high-pressure type, which uses direct steam from the boiler with pressure around 10.8 kg/cm², and the low-pressure type, which utilizes a vacuum pump to reduce pressure in the evaporator so it can use low-temperature heating media. The low-pressure type offers greater energy efficiency because it can utilize waste heat from the main engine cooling system. Fresh water generator system maintenance is a critical aspect that is often overlooked. Kurniawan and Ar-ridho (2024) emphasize the importance of a structured performance-monitoring system for optimizing freshwater production aboard ships. Regular cleaning of critical components, such as evaporator plates, filters, and heat exchangers, is required to prevent gradual system performance degradation.

This research addresses a real case that occurred on the vessel MV. Top Diligence, where fresh water production decreased from a normal capacity of 20-23 tons per day to only about 14 tons per day. This production decrease was caused by insufficient vacuum in the freshwater generator system, low ejector pump pressure (only 1.5 bar), and corrosion-related leaks in the seawater pipe. This condition requires proper identification and effective repair actions to restore production capacity to optimal conditions. The purpose of this research is to identify the causes of decreased freshwater production in the freshwater generator and to

analyze efforts to address these problems. A freshwater generator is an installation or unit that produces fresh water from seawater through distillation (Suparwo, 2019). According to Budi (2013), a freshwater generator is a device that produces fresh water from seawater via vacuum distillation. Jackson and Morton (2003) explain that the basic principle of vacuum distillation is the use of the relationship between pressure and the boiling point of liquids. Under normal conditions, water evaporates at 100°C and 1 atm. However, reducing the pressure in the system can significantly lower the boiling point of water. In a freshwater generator, pressure is reduced so that seawater can evaporate at approximately 60°C, enabling the use of waste heat from the main engine cooling system. Suparwo (2019) states that the seawater vapor produced is then cooled by condensation within the distiller or condenser, producing condensed water, or condensate. This process involves heating the liquid until it reaches the boiling point. The vapor produced is then directed to the condenser, which uses seawater as a cooling medium, allowing heat absorption and condensing the vapor into liquid (condensate). Kurniawan and Ar-ridho (2024) emphasize the importance of a structured performance-monitoring system for optimizing freshwater production aboard ships. Planned preventive maintenance can prevent major damage and maintain system operational efficiency.

METHOD

This research uses a qualitative case study approach to conduct an in-depth analysis of the phenomenon of decreased freshwater production in the vessel's freshwater generator. Top Diligence. According to Yin (2018), a case study is an appropriate research method for investigating contemporary phenomena in real-life contexts, especially when the boundary between the phenomenon and its context is not clear. This approach allows researchers to comprehensively understand the factors affecting system performance and identify appropriate solutions.

The research was conducted on the vessel MV. Top Diligence, a Hong Kong-flagged cargo ship built in 2018, owned by Run Da Shipping Co., Limited, with management by Top Wisdom Shipping Co Limited. Data collection was carried out during the sea practice period from October 22, 2024, to August 8, 2025. An intensive observation focus was conducted from December 25, 2024, to January 22, 2025, during which a significant decrease in fresh water production occurred.

The research uses methodological triangulation to enhance data validity. Sugiyono (2017) states that triangulation is a data collection technique that combines data from multiple sources. The techniques used include: observation conducted directly with the researcher involved in fresh water generator operations and maintenance. Creswell (2014) explains that participatory observation allows researchers to gain a deep understanding through direct experience. Observed aspects include operational processes, technical parameters (vacuum pressure, temperature, flow rate), physical component conditions, and maintenance procedures. Semi-structured interviews were conducted with the Third Engineer, the Chief Engineer, and related crew members. Kvale and Brinkmann (2009) state that qualitative interviews aim to understand subjects' experiences and the meanings they give to those experiences. Interviews covered operational history, problems encountered, troubleshooting procedures, and evaluation of corrective actions. Document analysis was performed on the Daily Record Book, Planned Maintenance System (PMS), Instruction Manual Book, and Machinery History Card. Bowen (2009) states that document analysis is a systematic procedure for reviewing documents that provide background data and historical context.

DISCUSSION

The freshwater generator that is the object of this research is a DX- α series system manufactured by DongHwa Entec Engineering Co., Ltd., installed on the vessel MV. Top Diligence. This system uses the vacuum distillation principle by utilizing waste heat from the main engine jacket cooling water as the heating medium. According to Shimizu (2021), using waste heat from diesel engines not only increases ship energy efficiency but also reduces operational emissions. Under normal conditions, the system is capable of producing 20-23 tons of fresh water per day with standard operational parameters, including a vacuum pressure of 0.9 bar, an ejector pump pressure of 3-3.5 bar, a heating water inlet temperature of 60-70°C, and a product salinity below 10 ppm. This capacity aligns with the recommendations of Jackson and Morton (2003), who state that production capacity must meet daily requirements with a safety margin to ensure continuity of ship operations. Based on the daily record book, a significant decrease in fresh water production began on January 4, 2025. Production data showed a gradual decline from normal conditions of 20,071 liters/day (December 26, 2024) to 13,882 liters/day (January 11, 2025), representing a decrease of 30.8%. This consistent decline pattern indicates progressive degradation of system performance.

Sirman and Syahril (2023) state that gradual production decline usually indicates problems with heat transfer efficiency or a decrease in system vacuum, unlike the drastic decreases typically caused by major component failure. The pattern observed in this research is consistent with those findings, where the decrease occurred gradually over an 8-day period. Examination of operational parameters revealed several significant deviations from normal conditions:

a. Vacuum Pressure

System vacuum pressure decreased from the standard 0.9 bar to approximately 0.6-0.7 bar. This decrease in vacuum directly impacts evaporation efficiency. Narto (2019) explains that optimal vacuum conditions are critical for determining evaporation process efficiency and the amount of fresh water produced, because low vacuum increases the boiling point of seawater, making the evaporation process less efficient.

b. Ejector Pump Pressure

Ejector pump pressure dropped drastically from the standard 3-3.5 bar to only 1.5 bar. According to DongHwa Entec technical documentation (n.d.), the ejector pump plays a crucial role in maintaining vacuum conditions by extracting air and non-condensable gases from the system. The decrease in ejector pressure directly affects the system's ability to maintain a vacuum.

c. Heat Transfer Efficiency

Although the heating water temperature remained within the normal range (60-70°C), the temperature difference between the condenser inlet and outlet decreased, indicating an obstruction to heat transfer.

Using the 5 Whys Analysis method and physical inspection, three main causes of production decrease were successfully identified:

a. Seal Damage on Evaporator Plate

Visual inspection after evaporator disassembly found damage to the gasket/seal connecting the evaporator plates. This damage caused internal leakage, reducing the system vacuum. Suparwo (2001) explains that seal integrity is crucial in vacuum systems, as even the smallest leak can disrupt vacuum conditions and reduce evaporation efficiency.

b. Fouling on Evaporator Plate

Significant accumulation of salt scale and mineral deposits was found on the evaporator plate surface. This scale layer acts as an insulator, inhibiting heat transfer from the heating

medium to seawater. Abou Elmaaty et al. (2017) state that fouling is one of the main problems in heat exchangers that can reduce the heat transfer coefficient by up to 50% or more, depending on the thickness and type of deposits. Visual analysis showed that the formed scale was 2-5 mm thick, with an uneven distribution on the plate surface. A thicker scale was found in areas with higher temperatures, consistent with Suparwo's (2001) theory, which states that scale formation is accelerated at high temperatures where salt solubility decreases.

c. Decreased Ejector Pump Performance

Examination of the ejector pump revealed wear on the impeller and deposit accumulation on the ejector nozzle. This condition reduced pump discharge pressure and ejection effectiveness. Jackson and Morton (2003) explain that worn or clogged impellers will reduce head pressure and flow rate, thereby reducing the ability to create a vacuum in ejector systems.

Using an Ishikawa Diagram, the causes were grouped into four main categories:

a. Material

- Inadequate gasket/seal quality for continuous operation conditions
- Seawater characteristics with high mineral content accelerate scaling
- Corrosion on seawater pipes due to high salinity

b. Method

- Cleaning intervals are too long (not appropriate for seawater conditions)
- Non-optimal chemical cleaning procedures
- Lack of regular vacuum parameter monitoring

c. Machine

- Evaporator plate design that facilitates deposit accumulation
- Natural component wear due to operational age
- Limited ejector pump capacity under high fouling conditions

d. Man

- Lack of crew awareness of early warning signs
- Limited skills in preventive maintenance
- Delayed response to parameter deviations

Okes (2009) states that categorization of causes using a fishbone diagram helps identify the most effective intervention areas and prevents problem recurrence.

Based on diagnostic results, systematic troubleshooting procedures were performed, including:

a. Shutdown and System Isolation

The fresh water generator system was shut down and isolated from the heating and cooling systems in accordance with safety procedures. Jackson and Morton (2003) emphasize the importance of proper shutdown procedures to avoid thermal shock to components and ensure personnel safety.

b. Disassembly and Inspection

The evaporator was disassembled in stages with visual documentation at each stage. Visual inspection confirmed extensive fouling and seal damage. This process involved the Third Engineer, Fitter, and researcher (Cadet) under the Chief Engineer's supervision.

c. Cleaning and Replacement

Based on inspection findings, two types of intervention were performed: Mechanical Cleaning: Manual scale cleaning using wire brushes and scrapers. This method was

chosen due to limited availability of chemical cleaners aboard the ship. Suparwo (2001) explains that mechanical cleaning is effective for hardened scale, but must be done carefully to avoid damage to the plate surface. Component Replacement: Replacement of damaged gasket/seal with new ones according to manual specifications. DongHwa Entec (n.d.) recommends using a gasket material that is resistant to high temperatures and seawater chemical degradation.

d. Ejector Pump Maintenance

Cleaning of the impeller and ejector nozzle from deposits was performed, along with clearance and alignment inspection. Kurniawan and Ar-ridho (2024) emphasize the importance of ejector pump maintenance, as it plays a crucial role in maintaining system vacuum conditions.

The entire repair process was documented visually and in writing. Documentation included pre-cleaning conditions showing thick scale on evaporator plates, the manual cleaning process, the damaged gasket condition, and the post-repair condition. This documentation is important for learning purposes and future maintenance reference, consistent with continuous improvement principles in maintenance management (NSOS, 2006).

After completion of repairs, the system was operated again, starting January 18, 2025. Intensive monitoring was conducted for 5 days to evaluate intervention effectiveness. Production data showed significant improvement:

- January 19, 2025: 20,241 liters (46% increase from pre-intervention condition)
- January 20, 2025: 20,915 liters
- January 21, 2025: 21,163 liters (reached peak production)
- January 22, 2025: 20,955 liters

The average post-intervention production was 20,819 liters/day, showing recovery to normal levels and even slightly exceeding the baseline before the problem occurred. This increase confirms that the intervention successfully addressed the root causes.

Operational parameters also showed recovery to standard conditions:

- Vacuum pressure: returned to 0.88-0.92 bar
- Ejector pump pressure: recovered to 3.2-3.4 bar
- Product salinity: consistently below 5 ppm (well below the 10 ppm limit)
- Temperature differential in the condenser: showed improved heat transfer efficiency

Sirman and Syahril (2023) state that recovery of vacuum and pressure parameters are primary indicator of successful repairs in freshwater generator systems. The data obtained is consistent with that statement.

Although detailed specific energy measurements were not performed, observations showed that steam or hot water consumption to produce the same volume of fresh water decreased after repairs. This is consistent with Shimizu's (2021) finding that clean, well-maintained systems have much better energy efficiency than systems with fouling.

Further analysis revealed that the ship was sailing in areas with seawater characteristics conducive to scaling. The sailing route from Africa to China passed through waters with high salinity and relatively high sea surface temperatures (28-32°C). Amin et al. (2023) explain that the combination of high salinity and high temperature accelerates mineral precipitation and scale formation in desalination systems.

The ship operated continuously during that period without an extended port stay that would allow scheduled maintenance. Jackson and Morton (2003) state that continuous operation without adequate maintenance windows can accelerate system performance deterioration, especially in systems sensitive to fouling, such as fresh water generators.

The review of the Machinery History Card revealed that the last evaporator cleaning was performed 6 months prior to the incident. This interval may have been too long for the seawater

conditions encountered. Kurniawan and Ar-ridho (2024) recommend adjusting maintenance intervals based on actual operational conditions rather than following standard schedules.

Based on research findings, PMS revision for the freshwater generator is recommended by shortening the cleaning interval from 6 months to 3-4 months, or more frequently if operating in high-salinity waters. NSOS (2006) emphasizes that effective PMS must be adaptive to operational conditions and not rigidly follow standard manufacturer schedules.

Implementation of stricter monitoring of vacuum parameters and ejector pressure as an early warning. A 10% decrease from normal values should trigger investigation and assessment. Kurniawan and Ar-ridho (2024) state that real-time monitoring systems with alert mechanisms can prevent prolonged performance deterioration.

Research findings indicate the need for greater crew awareness and technical skills in troubleshooting freshwater generators. Jackson and Morton (2003) emphasize that crew competency in maintenance and troubleshooting is a critical factor in the reliability of ship machinery.

The availability of critical spare parts, such as gaskets/seals and chemical cleaners, needs to be ensured in the ship's store. Delays in repairs due to a lack of spare parts can prolong downtime and affect ship operations.

The findings of this research are consistent with those of Sirman and Syahril (2023), who also identified fouling and decreased vacuum as the main causes of reduced fresh water production on MT. Gloria Sentosa. However, this research makes additional contributions through detailed documentation of the troubleshooting process and quantification of post-intervention improvement.

This research also reinforces Suparwo's (2001) findings on the importance of regular cleaning and seal/gasket maintenance for optimal performance of vacuum distillation systems. The difference in seawater temperature between the research location (28-32°C) and standard conditions (25°C) shows that environmental factors significantly influence fouling rates.

CONCLUSION

Based on the results of research and discussion regarding the identification and efforts to overcome the decrease in freshwater production in the freshwater generator on the vessel MV. Top Diligence, the decrease in fresh water production from normal conditions of 20-23 tons/day to 13.8 tons/day (a decrease of 30.8%) was caused by three interrelated main factors. First, seal/gasket damage on the evaporator plate caused internal leakage and decreased system vacuum. Suparwo (2001) confirms that seal integrity is crucial in vacuum systems because even the smallest leak can disrupt vacuum conditions and reduce evaporation efficiency. Second, fouling or salt scale accumulation, with a thickness of 2-5 mm, on the evaporator plate surface, inhibits heat transfer. Abou Elmaaty et al. (2017) state that fouling can reduce the heat transfer coefficient by up to 50%. Third, decreased ejector pump performance due to impeller wear and deposit accumulation, reducing pressure from the standard 3-3.5 bar to only 1.5 bar, making it unable to maintain optimal vacuum conditions.

The decrease in fresh water production significantly impacted system operational parameters. Vacuum pressure decreased from the standard 0.9 bar to 0.6-0.7 bar, which directly affected evaporation efficiency. Narto (2019) explains that optimal vacuum conditions are critical for determining the efficiency of the evaporation process and the amount of fresh water produced. The decrease in vacuum raised the seawater boiling point, making the evaporation process less efficient even though the heating medium temperature remained within the normal range of 60-70°C. This confirms that the vacuum factor is more dominant than temperature in determining the performance of a vacuum distillation system.

The corrective actions taken proved highly effective in restoring fresh water production. Interventions included mechanical cleaning of scale on evaporator plates using wire brushes, replacement of damaged gaskets/seals, and ejector pump maintenance. Post-intervention monitoring results showed production recovered to normal levels, averaging 20.8 tons/day, a 46% increase from pre-repair conditions. Sirman and Syahril (2023) state that recovery of vacuum and pressure parameters are primary indicator of successful repairs in freshwater generator systems. Operational parameters also returned to standard conditions, with a vacuum pressure of 0.88-0.92 bar, an ejector pump pressure of 3.2-3.4 bar, and a product salinity consistently below 5 ppm.

Operational environmental characteristics significantly influenced the rate of system performance degradation. Navigation in waters with high salinity and sea surface temperatures of 28-32°C accelerated scale formation. Amin et al. (2023) explain that the combination of high salinity and high temperature accelerates mineral precipitation and scale formation in desalination systems. Continuous operation without adequate maintenance windows also contributed to progressive fouling accumulation. Jackson and Morton (2003) confirm that continuous operation without adequate maintenance windows can accelerate deterioration in system performance, especially in systems sensitive to fouling.

This research confirms the importance of implementing a planned maintenance system (PMS) that is adaptive to operational conditions. The previously applied 6-month cleaning interval proved too long for the operational conditions encountered. Kurniawan and Ar-ridho (2024) recommend adjusting maintenance intervals based on actual operational conditions rather than following standard schedules. NSOS (2006) emphasizes that effective PMS must be adaptive to operational conditions and not rigidly follow standard manufacturer schedules. Early detection through monitoring of critical parameters such as vacuum pressure and ejector pressure can prevent prolonged performance degradation.

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