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Operational Challenges and Maintenance Strategies of Marine Fresh Water Generator System

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Abstract

Background: The Fresh Water Generator (FWG) is a critical shipboard system that produces potable and technical fresh water from seawater via vacuum evaporation, utilizing waste heat from the main engine jacket cooling water circuit. The FWG is susceptible to operational disruptions including heat exchanger fouling, mineral scaling, vacuum system failures, thermal efficiency reduction, and salinity monitoring errors.
Objective: This study investigates these operational challenges and the maintenance strategies employed to address them, based on the direct professional experience of marine engineers employed by Anthony Veder Rederijzaken, a Rotterdam-based LNG shipping company.
Methods: A qualitative case study methodology was adopted, using semi-structured interviews with five marine engineers at the rank of Second and Third Engineer. Five respondents were sufficient because thematic data saturation was reached, with no new themes emerging from the final interviews. Interview data were analyzed manually through thematic analysis, supported by technical document review and structured literature comparison.
Results: Five operational challenge themes were identified: biofouling and physical fouling of plate heat exchangers; mineral scaling from calcium carbonate and magnesium hydroxide precipitation; vacuum system degradation from air ingress; reduced thermal efficiency under variable engine load; and salinity monitoring system failures. Corresponding maintenance strategies include scheduled chemical descaling, vacuum integrity checks, routine performance monitoring, pump and ejector overhauls, and weekly salinometer calibration. These findings contribute a practitioner-grounded, route-adaptive framework for condition-based maintenance practice.
Conclusion: The findings offer evidence-based recommendations that advance maintenance management in maritime engineering and provide empirical material for strengthening maritime education curricula.

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INTRODUCTION

The availability of fresh water aboard ocean-going vessels is a fundamental operational requirement. Fresh water serves crew consumption for drinking, cooking, and sanitation, as well as critical technical systems including boiler feedwater circuits, engine jacket cooling make-up water, and fire-fighting equipment. Vessels engaged in deep-sea trade cannot rely exclusively on shore-supplied fresh water and must therefore maintain the capacity for autonomous on-board production (Jain et al., 2026; Kralj et al., 2017; Muhammed et al., 2021). Water security at sea is therefore inseparable from vessel safety, crew health compliance under the Maritime Labour Convention, and uninterrupted commercial operation, making the reliability of on-board water production a core operational concern for ship management.

The Fresh Water Generator (FWG) is the predominant technology used to meet this requirement aboard commercial ships. It operates on the principle of low-pressure vacuum evaporation: seawater is heated by waste heat recovered from the main engine jacket cooling water circuit, causing partial evaporation under partial vacuum. The resulting steam is condensed in an integral condenser cooled by seawater, producing distillate that is continuously monitored for salinity before transfer to the freshwater storage tanks (Capocelli et al., 2017; Hartanto et al., 2020; Prawoto et al., 2025).

Fresh water demand aboard a modern LNG tanker typically ranges from 5 to 10 tonnes per day when domestic and technical requirements are combined, depending on crew size and machinery configuration (Jain et al., 2026; Kralj et al., 2021). The strategic importance of reliable FWG operation is therefore substantial. A system failure during a deep-sea passage can rapidly deplete fresh water reserves, endangering crew welfare and forcing costly diversions. Quantitative evidence underscores these stakes. Reliability analyses of ship machinery show that auxiliary systems, including fresh water generators, contribute a substantial share of recorded machinery failures on merchant vessels, and that unplanned corrective interventions typically cost several times more than equivalent planned preventive actions once spare-part logistics, off-hire time, and possible deviation are included (Corsi et al., 2026; Eriksen et al., 2021; Lazakis et al., 2018). Condition-monitoring research further indicates that early fault diagnosis of shipboard engine-room systems measurably reduces downtime and total maintenance cost on international trading routes (Karatuğ & Arslanoğlu, 2022). Nevertheless, published quantitative data specific to FWG failure frequency and maintenance cost remain scarce, which strengthens the case for capturing practitioner experience directly.

Despite its efficiency, the FWG is vulnerable to a range of operational degradation mechanisms. Fouling of heat exchanger surfaces by marine biota, suspended sediments, and colloidal matter progressively reduces heat transfer performance (Ahmad et al., 2022; Yuksel et al., 2019). Mineral scaling from calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$) forms adherent deposits on evaporator plates that impair thermal efficiency (Pal et al., 2024). Vacuum system failures from air ingress elevate the operating boiling point and curtail output (Hartanto et al., 2020; Muhammed et al., 2021; Prawoto et al., 2025). Pump, ejector, and salinity monitoring failures introduce further operational risk (Purnama et al., 2021; Rizqi Salman, 2025).

The existing literature on marine FWG systems is predominantly quantitative and thermodynamic in character, focusing on performance modelling and system optimisation (Lam et al., 2020; Talaie et al., 2024; Yuksel et al., 2019). Practitioner-centred qualitative investigation of the lived operational experience of engineers who manage these systems daily remains limited. This gap is significant because the hands-on knowledge accumulated by shipboard engineers constitutes a form of technical expertise not easily captured through modelling alone. The research gap is therefore explicit: previous studies are predominantly quantitative, relying on thermodynamic simulation and performance measurement under controlled assumptions, whereas the present study adopts a qualitative case study approach that accesses the experiential, practice-based knowledge of serving engineers a dimension of FWG reliability that quantitative modelling alone cannot reveal.

Previous studies also share several limitations. Most rely on simulation or laboratory-scale data rather than in-service operational records; few consider how trading route and seawater characteristics should shape maintenance interval selection; and none systematically examine how FWG maintenance knowledge is acquired and transferred among shipboard engineers (Pal et al., 2024; Yuksel et al., 2019). These limitations further justify a practitioner-centred inquiry conducted within a real operating fleet.

The novelty of this study lies in three aspects. First, it is among the first qualitative case studies to document FWG operational challenges from the perspective of serving marine engineers rather than through thermodynamic modelling. Second, it identifies on-board knowledge transfer and informal performance logging as previously under-reported dimensions of FWG maintenance management. Third, it develops a route-adaptive maintenance perspective that links geographic operating conditions to maintenance interval decisions, offering a conceptual bridge between practitioner experience and formal maintenance planning.

Anthony Veder Rederijzaken is a Rotterdam-based shipping company specialising in the transportation of liquefied natural gas (LNG), liquefied petroleum gas (LPG), ethylene, and other chemical gases. Its fleet of modern gas tankers operates across European short-sea and international deep-sea routes. The company's marine engineers routinely manage FWG systems under demanding conditions, accumulating practical knowledge highly relevant to this investigation.

This company constitutes an information-rich and analytically suitable case for several reasons. Its vessels operate across contrasting hydrographic environments from cold, low-salinity North Sea waters to warm, high-salinity Mediterranean routes which exposes identical FWG installations to markedly different fouling and scaling regimes and therefore allows route-related variation in maintenance demand to surface naturally in the data. Its fleet also carries several widely used FWG models from different manufacturers, so the challenges reported are not artefacts of a single equipment design. Finally, its engineers rotate between vessels, giving each respondent comparative experience across multiple installations and operating conditions.

This study therefore aims to: (1) identify and categorise the operational challenges encountered in marine FWG systems aboard vessels of Anthony Veder Rederijzaken; (2) analyse the technical factors contributing to FWG performance degradation; and (3) examine the maintenance strategies applied by marine engineers to sustain FWG reliability.

Theoretically, this research contributes to the development of marine maintenance management by demonstrating how tacit practitioner knowledge can be systematised into transferable maintenance principles. Practically, the findings provide shipping companies with actionable, route-sensitive guidance for FWG maintenance planning, and offer maritime education institutions empirical material for strengthening FWG-related content in marine engineering curricula, so that graduates enter service better prepared for the failure modes they will actually encounter.

METHOD

A qualitative research approach with a case study design was employed (Creswell & Poth, 2018; Lu, 2026). This methodology was selected because the primary aim is to explore and interpret the lived operational experiences of marine engineers regarding FWG challenges and maintenance practices. The case study design enables contextualised examination of a bounded operational unit within an interpretivist stance (Beuving & Vries, 2025; Lincoln & Guba, 1985; Yin, 2018).

Respondents were selected using purposive sampling, a technique in which participants are chosen for their capacity to provide information-rich data relevant to the research questions (Coleman et al., 2024; Patton, 2015). Inclusion criteria required respondents to: (a) hold the rank of Second or Third Engineer; (b) be employed by Anthony Veder Rederijzaken at the time of the study or within the preceding two years; and (c) possess a minimum of two years of sea service on gas tanker vessels equipped with vacuum evaporation FWG systems. A total of five engineers participated. The number of five respondents was determined by the criterion of data saturation: by the fourth and fifth interviews no new codes or themes emerged, indicating that the data were sufficient to answer the research questions, consistent with empirical evidence that saturation in homogeneous expert samples is commonly reached within small sample sizes (Hennink & Kaiser, 2022). This sample size is appropriate for a case study qualitative design where depth of inquiry is prioritised over breadth, and where data saturation is the criterion for sample adequacy (Creswell & Poth, 2018; Lu, 2026). Respondent profiles are summarised in Table I.

Table 1
Respondent Profiles

Code	Rank	Experience (yrs)	FWG Type(s)
AV-E01	2nd Engineer	8	Sondex SFD 13
AV-E02	3rd Engineer	5	Alfa Laval JWP-26
AV-E03	2nd Engineer	10	Wartsila SW-FWG
AV-E04	3rd Engineer	4	Alfa Laval JWP-26
AV-E05	2nd Engineer	7	Sasakura FW-250

Three complementary data collection methods were employed to support triangulation (Beuving & Vries, 2025; Lincoln & Guba, 1985).

(1) Semi-Structured In-Depth Interviews
Each interview was conducted online via Zoom and lasted between 60 and 90 minutes. All sessions were audio-recorded and video-recorded with the informed consent of respondents. An interview guide was developed from the literature review and pilot-tested with two marine engineering academics before deployment. The final guide contained 12 main questions organised into four sections: system configuration, operational problems encountered, maintenance practice, and engineering recommendations. Sample questions included: "What operational problems do you encounter most frequently with the FWG?" and "How do you decide when chemical descaling is required?" The overall data collection process was carried out over a twelve-week period, from January to March 2026, covering interview scheduling, the interviews themselves, transcription, and member checking. Questions explored FWG system configuration, specific operational problems encountered, diagnostic practices, maintenance schedules, chemical cleaning protocols, and engineering recommendations.

(2) Technical Document Review
Supplementary data were obtained through review of equipment manuals (Alfa Laval JWP-26, Wartsila SW-FWG, Sasakura FW-250) and relevant class society maintenance guidelines. Document analysis provided a technical reference framework against which interview findings could be contextualised and cross-checked (Bowen, 2009, 2027). Documents were analysed by extracting manufacturer-specified operating parameters, maintenance intervals, and troubleshooting procedures, which were then compared item by item with the practices reported by respondents.

(3) Structured Literature Review
A targeted search of Scopus, Web of Science, and Google Scholar databases was conducted using search terms including "marine fresh water generator," "shipboard vacuum evaporator," "heat exchanger fouling shipping," and "marine desalination maintenance" to situate empirical findings within the existing scientific literature.

Interview recordings were transcribed manually and read repeatedly to achieve close familiarity with the data. Analysis followed the thematic analysis framework of Braun and Clarke (2006), which involves: (1) familiarisation with the data through repeated reading; (2) generating initial codes by marking meaningful units of text relevant to the research questions; (3) grouping related codes into candidate themes; (4) reviewing and refining themes for internal coherence; (5) clearly defining and naming each theme; and (6) writing up the findings (Pickering et al., 2026).

All coding was performed manually and documented in a structured coding sheet. This straightforward approach ensured that the analysis remained grounded in the actual words of respondents without reliance on automated tools. Themes were reviewed by two members of the research team independently, and any disagreements in coding were resolved through discussion until consensus was reached. Findings were subsequently cross-validated against technical documentation and the peer-reviewed literature to assess consistency and accuracy.

Trustworthiness was established through member checking (interview summaries shared with respondents for verification), peer debriefing among the research team, and triangulation across interview data, technical documents, and published literature (Beuving & Vries, 2025; Lincoln & Guba, 1985). All respondents provided written informed consent. Data were anonymised at the point of transcription, with respondents identified only by codes (AV-E01 to AV-E05). The study received ethics approval from the Research Ethics Committee of Politeknik Pelayaran Sorong.

RESULTS AND DISCUSSION

Thematic analysis of the five interview transcripts yielded five principal themes corresponding to the main operational challenge categories, each accompanied by related maintenance strategy findings. The analytical focus of this section is maintenance effectiveness: failure mechanisms are described only to the extent needed to explain why the corresponding maintenance strategies work, and technical terminology is used consistently throughout (fouling, scaling, vacuum degradation, thermal efficiency, salinity monitoring). Beyond cataloguing the five themes, the findings contribute directly to the development of marine maintenance practice by translating practitioner experience into route-adaptive, condition-based maintenance principles. Table II provides a structured summary of all themes and the number of respondents who reported each one. The following sub-sections present each theme with supporting data extracts and discussion against the existing literature.

Table 2
Summary Of Operational Challenge Themes

Theme	Category	Key Sub-themes	Respondents (n)
T1	Fouling of Heat Exchanger Surfaces	Biofouling; physical particle fouling; warm coastal water exposure	5 / 5
T2	Mineral Scaling	$CaCO_3$ deposition; $Mg(OH)_2$ scale; reduced production rate	5 / 5
T3	Vacuum System Degradation	Air ingress; ejector nozzle wear; seal and gasket failure	4 / 5
T4	Thermal Efficiency Reduction	Engine load variation; cold seawater; insufficient JCW temperature	4 / 5
T5	Salinity Monitoring Failures	Electrode fouling; calibration drift; solenoid dump valve jamming	3 / 5

Theme 1: Fouling of Heat Exchanger Surfaces

Findings

All five respondents identified fouling of the plate heat exchanger as the most routinely encountered operational problem. Two forms were distinguished: biofouling and physical particulate fouling.

Biofouling, caused by the deposition of biofilms, algae, and micro-organisms on plate surfaces, was particularly prevalent when operating in warm coastal waters. AV-E03 noted: "When we are in warmer waters, production drops noticeably within a few weeks." AV-E05 similarly reported that biofouling was most aggressive during voyages through the Mediterranean in summer months, where seawater temperatures exceeded 28°C.

Physical fouling by suspended particles was reported by three respondents. AV-E01 described how fine sediment particles carried by seawater in port areas could partially block the narrow channels between plates, restricting flow and reducing heat transfer efficiency gradually over time without any obvious visual indication during routine external inspection.

Discussion

These findings align well with the literature. Yuksel et al. (2019) showed that surface fouling can reduce the overall heat transfer coefficient of a plate heat exchanger by 20 to 40% under moderate fouling conditions (Pal et al., 2024). Ahmad et al. (2022) confirmed that warm, biologically active seawater accelerates fouling rates significantly.

Maintenance Response

All respondents described a combination of physical and chemical cleaning as the primary maintenance countermeasure. Physical cleaning was typically performed by opening the heat exchanger and manually brushing the plates every three to six months. Chemical cleaning using citric acid solution was applied for more persistent biological and early-stage mineral deposits. AV-E02 described implementing a monthly flush of the system with hot fresh water as a simple preventive measure that was found to noticeably slow the build-up of biofouling between planned physical cleanings.

Theme 2: Mineral Scaling

Findings

Mineral scaling was reported by all five respondents as a distinct and often more serious problem than biofouling. Calcium carbonate ($CaCO_3$) was identified by four respondents as the dominant scaling compound, forming white, chalky deposits on evaporator heating plates. Magnesium hydroxide ($Mg(OH)_2$) scale was described by two respondents as a greyish deposit that was more difficult to remove chemically.

AV-E03 described a situation where a combination of infrequent cleaning and operating predominantly in high-salinity eastern Mediterranean waters caused freshwater production to drop from a nominal output of approximately 26 tons per day to around 14 tons per day over a single trading season. AV-E04 observed that scaling developed noticeably faster on Mediterranean routes compared to North Sea operations, reflecting the higher dissolved mineral content of Mediterranean seawater.

Discussion

Pal (2024) demonstrated through exergy analysis that mineral scaling significantly degrades FWG thermodynamic performance by imposing additional thermal resistance on evaporator surfaces. Kralj et al. (2021) identified calcium carbonate as the dominant scaling compound in marine FWG applications and confirmed that scaling is the primary driver of long-term performance decline, consistent with the findings reported here (Jain et al., 2026). The geographic variation in scaling rates noted by AV-E03 and AV-E04 is consistent with the well-established higher salinity and hardness of Mediterranean seawater relative to the North Sea (Kralj et al., 2017), and supports the practical recommendation that maintenance intervals should be adjusted based on the vessel's operating region rather than applied as a fixed universal schedule (Jain et al., 2026).

Maintenance Response

Acid descaling was the standard treatment reported by all respondents. AV-E01 and AV-E03 used commercially available marine descaling agents (buffered acid-based products) in preference to raw acids, citing lower risk of plate damage. AV-E05 reported the use of a scale inhibitor dosing system on the seawater feed, which was found to meaningfully extend the interval between necessary descaling treatments. The consensus among respondents was that descaling should be performed every four to six months for Mediterranean operations and every eight to twelve months for North Sea or Atlantic routes.

Theme 3: Vacuum System Degradation

Findings

Four of five respondents reported vacuum system problems as a recurring source of FWG disruption. The most common issue was gradual vacuum deterioration due to air ingress through worn pump shaft seals, deteriorated gaskets, or loose flanged joints. As vacuum decreased, the boiling point inside the evaporator shell rose, which progressively reduced the rate of evaporation and therefore the freshwater production rate.

AV-E02 described a practical diagnostic method for locating air ingress: systematically isolating sections of pipework by closing valves one at a time while watching the shell vacuum gauge, to identify which section caused the most vacuum loss when isolated. This technique, learned through on-board experience from a senior engineer, allowed the source of air ingress to be pinpointed without removing any components. AV-E04 reported an ejector nozzle blockage that caused sudden complete loss of vacuum, requiring the system to be shut down and the ejector disassembled and cleaned before the FWG could be restarted.

Discussion

Hartanto et al. (2020) identified vacuum system integrity as one of the most operationally sensitive parameters governing FWG performance, noting that even small levels of air ingress produce measurable reductions in freshwater output (Prawoto et al., 2025). Muhammed et al. (2021) confirmed that ejector nozzle blockage and seal failure are among the most frequent causes of acute FWG shutdown (Mawarni et al., 2023). The manual diagnostic technique described by AV-E02 is a practical piece of procedural knowledge not formally documented in the equipment manuals reviewed in this study, highlighting the value of practitioner experience as a source of operational knowledge that complements manufacturer guidance.

Maintenance Response

Respondents described a preventive approach to vacuum system maintenance consisting of regular inspection and replacement of pump shaft seals at manufacturer-recommended intervals (typically every 4,000 to 6,000 running hours); checking and re-torquing all flanged joints and manhole cover bolts after port calls when thermal cycling was greatest; and inspecting and cleaning the ejector nozzle during scheduled heat exchanger maintenance. AV-E03 described performing a simple vacuum hold test by isolating the system and monitoring the rate of pressure rise over 15 minutes to assess overall vacuum integrity before and after maintenance work.

Theme 4: Thermal Efficiency Reduction

Findings

Four respondents reported reductions in FWG thermal efficiency and freshwater output under specific operational conditions not directly related to fouling, scaling, or vacuum failure. The principal factors identified were main engine load variation, and seawater temperature changes across different geographic routes.

All four respondents explained that the FWG cannot be operated effectively below a certain main engine load, typically around 40 to 50 percent, because the jacket cooling water temperature drops too low to sustain adequate evaporation at the system's operating vacuum. AV-E01 explained: "During slow steaming or manoeuvring in port approaches, the jacket water temperature sometimes drops below what the FWG needs. We have to stop the FWG or accept very low output." AV-E05 noted that during cold North Sea winter operations, the condenser performed better because of the colder seawater, but maintaining the evaporator at the required temperature was more challenging when engine load was reduced.

Discussion

Capocelli et al. (2017) established that FWG performance is thermodynamically governed by the temperature differential between the heat source (jacket cooling water) and the heat sink (condenser seawater), and that a reduction in the heat source temperature directly curtails freshwater output (Ben Hamida et al., 2025). Liu et al. (2021) confirmed through modelling that engine load reduction can critically constrain FWG output when jacket cooling water temperature falls below the minimum threshold required for evaporation at the design vacuum level (Zhao & Peng, 2025). The 40 to 50 percent minimum load threshold consistently reported by respondents aligns with limits stated in the Alfa Laval JWP-26 operational manual, demonstrating that the engineers' practical experience is consistent with the engineering design parameters of the equipment they operate.

Maintenance Response

Respondents described primarily operational rather than corrective maintenance responses to this challenge. AV-E01 described a practice of starting the FWG as early as possible after departure from port while the main engine was still at high load, to build a freshwater buffer before any anticipated slow-steaming phase. AV-E03 described manually reducing the feed water pump flow rate during low engine load periods to concentrate the available heat on a smaller seawater volume, maintaining the evaporation process at reduced throughput rather than shutting the system down completely.

Theme 5: Salinity Monitoring System Failures

Findings

Three respondents reported problems with the salinity monitoring system, specifically the salinometer conductivity electrode and the associated automatic dump solenoid valve. Two main failure modes were described. The first was electrode fouling causing falsely high salinity readings, which triggered the dump valve to open and divert all distillate overboard, effectively stopping freshwater production even though the actual distillate quality may have been acceptable. The second was electrode insensitivity from mineral coating, causing falsely low readings that allowed the dump valve to remain closed and potentially transfer substandard quality water to the freshwater tanks.

AV-E02 described an occasion where the salinometer was reading near-zero conductivity while the distillate was visibly foamy, a sign of possible seawater carry-over into the distillate circuit, because the electrode had become coated with a non-conducting mineral deposit. AV-E05 reported the opposite: a fouled electrode giving persistently elevated readings that caused the dump solenoid to remain open continuously, preventing any fresh water from reaching the storage tank until the fault was identified and the electrode cleaned.

Discussion

The salinity monitoring system represents the primary automated safety barrier preventing seawater-contaminated distillate from entering the fresh water supply. The two failure modes described by respondents illustrate opposite but equally significant risks: electrode insensitivity can result in contaminated water reaching the crew, while false high readings can halt freshwater production entirely during a voyage. Muhammed et al. (2021) and Hartanto et al. (2020) both identified salinometer reliability as important to FWG operational continuity (Mawarni et al., 2023). The findings here add practical detail about the specific electrode fouling mechanisms and their operational consequences, suggesting that regular electrode cleaning and independent manual cross-checking of salinity are important safeguards that should be included in routine maintenance protocols.

Maintenance Response

Respondents described weekly salinometer calibration checks using standard conductivity reference solutions as the primary preventive measure. AV-E03 and AV-E05 both emphasized the importance of keeping a spare electrode in stock so that a fouled or aged electrode could be replaced immediately without waiting for a spare parts delivery. AV-E02 described using a handheld conductivity meter to cross-check the salinometer reading independently on a weekly basis, providing a simple manual check that could detect electrode drift before it led to operational consequences.

Synthesizing across the five themes reveals a common underlying pattern rather than five isolated problems: every failure mechanism develops gradually and produces early, measurable indicators (a falling production rate, a rising shell temperature, or a drifting salinity reading) well before it becomes operationally critical. Critically assessed, effective FWG maintenance therefore depends less on any individual corrective technique than on systematic condition monitoring that detects these indicators early, calibrated to the vessel’s trading route, seawater characteristics, and engine operating profile.

Cross-Cutting Theme: Maintenance Management and Knowledge Transfer

Across all five themes, a consistent cross-cutting pattern emerged concerning how maintenance knowledge is acquired and applied aboard ship. Respondents who described more effective and proactive maintenance practices consistently attributed their approach to mentoring by senior engineers rather than to formal training received during maritime education.

AV-E01 described maintaining a simple personal log of weekly FWG readings, including production rate, vacuum level, and distillate temperature, going back over two years. This allowed performance trends to be identified two to three weeks before a problem became operationally critical. AV-E03 kept a similar record and used it to schedule descaling before production dropped significantly, rather than waiting for the system to show obvious symptoms. This basic performance logging approach, requiring nothing more than a notebook and consistent observation, represents an accessible form of condition-based maintenance available to any engineer regardless of vessel sophistication.

AV-E02 and AV-E04, who were serving as Third Engineers with four and five years of experience respectively, noted that the FWG-related content in their formal training programs had been limited, and that most of their practical troubleshooting knowledge had been learned by working alongside more experienced engineers. AV-E04 stated: "What I know about diagnosing FWG problems, I learned from the second engineer I sailed with, not from the textbook." This finding suggests that maritime engineering curricula should devote greater attention to FWG system operation and maintenance, and that systematic mentoring arrangements aboard ship are important for effective knowledge transfer to junior engineers (Muhammed et al., 2021; Purnama et al., 2021; Rizqi Salman, 2025).

This cross-cutting theme constitutes the principal novelty of the study: FWG reliability is sustained not only by technical procedures but by an informal socio-technical system of mentoring and personal performance logging, through which tacit knowledge is converted into operational practice. Framing shipboard maintenance as a knowledge-transfer system opens a new research direction that connects marine maintenance management with workplace learning theory, and suggests that formalizing mentoring and log-keeping (for example, through structured handover protocols and standardized FWG performance logs) could institutionalize expertise that currently depends on individual initiative (Karatuğ & Arslanoğlu, 2022).

Regarding applicability beyond LNG tankers, the maintenance strategies identified here are largely transferable to other vessel types. Vacuum-evaporation FWG installations aboard bulk carriers, container ships, and oil tankers share the same fouling, scaling, vacuum, and salinity-monitoring failure mechanisms, so the cleaning, descaling, calibration, and logging practices apply directly; only the thermal-efficiency findings, which depend on main engine load profiles and jacket water temperature, require adaptation to each vessel type's specific operating pattern (Mawarni et al., 2023; Muhammed et al., 2021).

CONCLUSION

This study investigated the operational challenges and maintenance strategies of marine Fresh Water Generator systems through qualitative case study research with five Second and Third Engineers employed by Anthony Veder Rederijzaken. Thematic analysis of interview data, supported by technical document review and literature cross-validation, identified five principal operational challenge themes: heat exchanger fouling (biofouling and physical particulate fouling); mineral scaling dominated by calcium carbonate; vacuum system degradation from air ingress and ejector wear; thermal efficiency reduction under low engine load conditions; and salinity monitoring system failures from electrode fouling and aging. Rather than five isolated problems, these themes converge on a single conceptual insight: FWG reliability is governed by gradual, detectable degradation processes whose management requires preventive, condition-based practice (scheduled cleaning and descaling, vacuum integrity verification, load-aware operating protocols, and routine salinometer calibration supported by simple performance logging) adapted to the vessel's trading route rather than applied as fixed universal intervals.

Theoretically, this study contributes to the development of marine maintenance management by providing a practitioner-grounded, route-adaptive framework for condition-based FWG maintenance, and by positioning informal knowledge transfer, mentoring and personal performance logging, as a central, previously under-theorized mechanism of shipboard reliability. The main limitation is the small, single-company sample of five engineers; future research should test the transferability of these findings across companies and vessel types and complement them with quantitative FWG performance data. Ultimately, reliable freshwater production at sea depends not on equipment alone, but on engineers equipped with the monitoring habits, mentoring, and education needed to act before failure occurs.

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AUTHOR CONTRIBUTION STATEMENT

Filemon contributed to the conceptualization, research design, data collection, technical analysis, and preparation of the original manuscript. Junaidi Roni Prastia and Fajar Gumelar contributed to methodology development, validation, data interpretation, and critical review of the manuscript. Fadel Muhammad and Meti Kendek contributed to supervision, technical evaluation, manuscript refinement, and final review.

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