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Article

Analysis of Performance Degradation of the Refrigeration System on MT Nolowati III

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A B S T R A C T

The refrigeration unit is a crucial auxiliary system on board the MT Nolowati III, responsible for provision preservation, food safety, and overall crew welfare. A critical operational issue identified on this vessel was the system's inability to maintain designated storage temperatures, specifically for the meat compartment (-10°C to -12°C) and the vegetable compartment (+4°C to +10°C). The primary objective of this study is to identify the root causes of this performance degradation and formulate preventive maintenance strategies. Utilizing a descriptive qualitative approach integrated with Root Cause Analysis (RCA)—specifically Fishbone Diagrams and Fault Tree Analysis (FTA)—the diagnostic findings reveal that the temperature instability was not caused by refrigerant leaks, but predominantly by a severely clogged condenser and thermostat malfunctions. These technical failures hindered heat transfer, disrupted the vapor compression cycle, and caused compressor overloading. Corrective actions, including comprehensive condenser cleaning and thermostat recalibration, successfully restored standard operating pressures (2.00-4.00 Kg/cm²) and optimal cooling capacity. The study concludes that rigorous adherence to preventive maintenance schedules and continuous monitoring of cycle parameters are imperative to ensure refrigeration reliability.

1. Introduction

Seafaring is a profession that is full of challenges, the need for the profession of seafarers in the world is increasing in direct proportion to the rate of increase in the world economy (Muhammad Zainuddin, 2021). Successful maritime operations rely on adequate infrastructure and stable vessel construction to ensure safety and timeliness (Cahyadi et al., 2019), a standard reinforced by Indonesian Law No. 17 of 2008 regarding vessel seaworthiness and crew welfare. A critical aspect of this welfare is the provision of high-quality food, which requires effective preservation to maintain crew health and productivity during long voyages. As such, the refrigeration system is indispensable for preventing food spoilage and ensuring onboard comfort, particularly in tropical regions (Roofiif & Anwar, 2025). Consequently, it is essential for ship engineers to possess the theoretical and practical expertise necessary to maintain, analyze, and repair cooling machinery (Santiko & Saifudin, 2022). By mastering these maintenance procedures, engineers can address technical disturbances effectively, thereby guaranteeing sustained operational efficiency and the well-being of the crew (Nurcahyo, 2018).

The maritime domain employs communications for a variety of critical applications, including safety, routine operational activities, and commercial applications such as trade and general correspondence (Prima Yudha et al., 2024). To ensure provision quality during voyages, vessels require reliable refrigeration systems capable of maintaining specific temperature ranges for different food categories. On the MT Nolowati III, precise thermal control is managed via thermo-expansion valves that regulate environments for vegetables between +4°C and +10°C, while meat storage requires significantly lower temperatures ranging from -10°C down to -30°C for deep freezing. The system operates by absorbing heat from the storage chambers to reach these set points, a critical process for preventing spoilage and maintaining the nutritional of supplies (Roofiif & Anwar, 2025).

However, operational failures often arise when the system cannot sustain the required temperatures, leading to potential food deterioration. Effective performance relies heavily on adherence to manufacturer manuals and regular maintenance of key components such as compressors, condensers, evaporators, and oil separators (Santiko & Saifudin, 2022). Observations indicate that negligence or improper maintenance protocols—specifically regarding the compressor and thermostat functions—can cause component incompatibility and system inefficiency, ultimately hindering the vessel's operational readiness (Nurcahyo, 2018; Suryapradana & Halim, 2024).

Given the critical need to maintain stable storage temperatures, this study investigates methods to optimize the refrigeration system, resulting in the research titled "Analysis of Performance Degradation of the Refrigeration System on MT Nolowati III." The primary objectives of this inquiry are to ensure the machinery remains in prime condition to preserve provision quality and to align all maintenance activities strictly with the instruction manual’s standards, thereby guaranteeing operational effectiveness and efficiency onboard.

Successful maritime operations rely on adequate infrastructure and stable vessel construction to ensure safety and timeliness, a standard reinforced by Indonesian Law No. 17 of 2008 regarding crew welfare. A critical aspect of this welfare is the provision of high-quality food, which requires effective preservation during long voyages. Consequently, reliable refrigeration systems capable of maintaining specific temperature ranges are indispensable for preventing food spoilage. On the MT Nolowati III, precise thermal control must be managed to regulate environments for vegetables (+4°C to +10°C) and meat (-10°C to -30°C). Despite its importance, operational failures frequently arise when aging refrigeration systems cannot sustain required temperatures due to component degradation. While previous studies have extensively covered general marine compressor mechanics, there is a distinct research gap regarding empirical failure analyses combining condenser fouling and thermostat malfunction in operational marine environments. Furthermore, observations indicate that suboptimal maintenance protocols often lead to component incompatibility and system inefficiency. Therefore, this study aims to address this gap by investigating the specific causes of performance degradation of the refrigeration system on the MT Nolowati III and proposing structured preventive maintenance strategies to ensure operational readiness

2. Literature Riview

2.1 Optimizatioon

Optimization is fundamentally defined as the process of elevating a system to its highest level of performance or "best" state. According to Hidayat and Irvanda (2022), this involves selecting the most effective solution from various alternatives to maximize objective functions without violating constraints, thereby reducing processing time and increasing profitability. This concept is further supported by Ali (as cited in Sopanah et al., 2023), who describes optimization as the achievement of desired results through efficiency, where the primary goals are either the maximization of benefits or the minimization of costs and operational delays. Ultimately, applying these principles to technical contexts—such as refrigeration machinery—facilitates faster decision-making and more reliable problem resolution by clearly identifying goals and overcoming operational barriers.

2.2 The Refrigeration System Degradation Mechanisms

The refrigeration system operates on the vapor compression cycle, utilizing a refrigerant to absorb and release heat. Performance degradation typically occurs when key components fail to facilitate this thermal exchange effectively.

The Compressor: Acting as the system's heart, it circulates refrigerant by creating pressure differentials. Degradation here often manifests as abnormal suction/discharge pressures and excessive noise, usually resulting from liquid slugging or poor lubrication.

The Condenser: This heat exchanger converts high-pressure vapor back into liquid. In maritime applications, fouling or scaling from seawater and debris accumulation acts as a thermal insulator. This fouling significantly reduces heat transfer, increases condensing temperature and pressure, and ultimately lowers the system's cooling capacity.

The Evaporator and Thermostat: The evaporator absorbs thermal energy to cool the designated space. The thermostat modulates this cycle based on thermal feedback. Thermostat malfunctions can lead to continuous compressor operation or excessive frost accumulation on evaporator fins, heavily impeding airflow and cooling efficiency..

2.3 The Compressor

The compressor functions as the heart of the refrigeration system, acting as a suction-pressure pump that circulates refrigerant by creating the pressure differentials necessary to drive flow from low to high-pressure zones. Ideally operating through an isentropic process, it prepares the gas for heat rejection in the condenser and is available in several configurations depending on operational requirements. These include reciprocating compressors, which use pistons to generate high pressure; rotary compressors, which utilize rotating screws or vanes to reduce gas volume; centrifugal compressors, which rely on dynamic force from spinning impellers; and axial compressors, which accelerate gas flow parallel to the axis using a series of rotors and stators.

2.4 The Condensor

The condenser functions as a vital heat exchanger within the refrigeration cycle, responsible for rejecting the heat absorbed by the evaporator and compressor to convert the refrigerant from a vapor back into a liquid state **(Roofiif & Anwar, 2025)**. In maritime applications, water-cooled variants are prevalent, though they require vigilant maintenance to prevent mineral scaling, which acts as a thermal insulator and diminishes cooling efficiency. These components are categorized based on their structural design and heat transfer method, ranging from indirect systems like **Shell and Tube**, **Flat Tube**, and **Surface condensers**—where the coolant and refrigerant remain separate—to **Jet condensers**, which facilitate rapid condensation through direct contact between the vapor and cooling water.

2.5 The Evaporator

The evaporator serves as the primary heat exchange unit in the refrigeration cycle, functioning to absorb thermal energy from the environment to vaporize the liquid refrigerant, effectively cooling the designated space. To accommodate various operational requirements, this component is designed in several configurations: the shell and tube evaporator is utilized for high-capacity applications such as maritime operations; the coil evaporator employs finned tubing to maximize air contact for air conditioning systems; the flooded evaporator offers high efficiency by fully submerging pipes in liquid refrigerant; and the shell and coil evaporator combines these designs to provide stable heat transfer for specialized industrial purposes.

2.6 The Capillary

As described by Mukhtar et al. (2025), the capillary tube serves as a critical metering device that regulates both the flow rate and pressure of the refrigerant by imposing significant hydraulic resistance. Physically, this tube is typically coiled around the filter drier before leading into the evaporator; this configuration serves a dual purpose by compacting the long tubing for easier installation and facilitating essential heat exchange between the compressor's suction line and the high-pressure liquid refrigerant to optimize thermal efficiency.

2.7 The Oil Separator

As detailed by Roofiif and Anwar (2025), the oil separator is a critical filtration device installed at the compressor outlet, designed to intercept lubricating oil that becomes entrained in the high-pressure refrigerant flow due to operational heat and pressure. Functioning on the principle of mechanical separation, the device decelerates and redirects the incoming mixture, causing the denser oil droplets to settle at the bottom while allowing the purified refrigerant vapor to proceed to the condenser. The collected lubricant is subsequently returned to the compressor's crankcase—often automatically via differential pressure—thereby preventing system-wide contamination and ensuring the compressor maintains adequate lubrication for sustained performance and operational longevity.

2.8 The Thermostat

As characterized by Suryapradana et al. (2024), the thermostat serves as a critical regulatory component that modulates coolant circulation to maintain ideal operating temperatures, initially restricting flow to facilitate rapid warm-up periods. In refrigeration applications, this device automates the compressor's duty cycle based on thermal feedback, ensuring energy efficiency while preventing excessive frost accumulation on evaporator fins that would otherwise impede airflow and degrade cooling capacity. Thermostat technologies vary widely to suit specific precision needs, ranging from mechanical bimetal strips and electromechanical pressure systems to advanced electronic units utilizing resistive sensors—such as NTC thermistors and RTDs—or programmable digital interfaces for time-based control.

2.9 The Expansion

As described by Roofiif and Anwar (2025), the expansion valve serves as the critical interface between the high-pressure and low-pressure sides of the refrigeration system, regulating the transition of refrigerant from the condenser to the evaporator. Its primary function is to throttle the flow of high-pressure liquid, significantly reducing its pressure to facilitate evaporation at lower temperatures, which is essential for effective heat absorption. By dynamically adjusting the refrigerant volume based on the specific thermal load of the cooling chamber, this component—available in configurations such as thermostatic valves, constant pressure valves, and capillary tubes—ensures the system operates efficiently across varying conditions.

2.10 The Accumulator

The accumulator serves as a vital protective component in direct expansion refrigeration systems, particularly in maritime applications, designed to temporarily store the mixture of liquid refrigerant and oil returning from the evaporator. Its primary function is to separate these phases to ensure that only vaporized refrigerant enters the compressor intake, thereby filtering out any remaining liquid. This segregation is critical for preventing "liquid slugging," a phenomenon where the intake of incompressible fluid creates extreme pressure spikes that can cause severe mechanical damage to internal components such as pistons, valves, and bearings.

2.11 The Freont Refrigerant

The evolution of refrigerant technology demonstrates a clear transition from chemical stability to environmental sustainability. Initially, R-12 (CFC) served as the industry standard due to its non-toxic properties, yet it was eventually banned under the 1987 Montreal Protocol for severe ozone depletion. Its successor, R-22 (HCFC), provided a temporary alternative with reduced ozone impact but is currently being phased out due to its contribution to global warming. Consequently, modern systems have shifted toward R-134a (HFC), which offers zero ozone depletion despite a high Global Warming Potential (GWP) and specific lubrication requirements, and R-290 (Propane), a natural refrigerant that boasts superior energy efficiency and negligible environmental impact, albeit requiring rigorous safety measures due to its flammability.

3. Research Methodology

This research was conducted onboard the MT Nolowati III during the author's sea service, employing a descriptive qualitative approach combined with structured Root Cause Analysis (RCA). The observation period occurred in August 2023 during a voyage from India to Singapore.

Data collection involved direct field observations of operational parameters (e.g., room temperature, suction/discharge pressure, and compressor current) and structured interviews. The interview participants were the Chief Engineer and Second Engineer, focusing on maintenance intervals, failure symptoms, and historical operational logs.

To process the data systematically, Fishbone (Ishikawa) Diagrams and Fault Tree Analysis (FTA) were utilized. The Fishbone Diagram was structured around four primary branches: Machine (compressor and fan condition), Method (maintenance schedules), Material (refrigerant and filter status), and Environment (ambient engine-room temperature). FTA was subsequently applied to map the logical failure pathways leading to the top event: "Inability to reach designated storage temperatures". .

4. Results and Discussion

4.1 Failure Symptoms and Observation Observation

On August 23, 2023, the vessel experienced a significant cooling failure leading to decreased cooling performance (increased storage temperatures). The Mitsubishi Electric semi-hermetic compressor (using R-22 refrigerant) operated unstably, deviating from the normal pressure parameters of 2.00-4.00 Kg/cm^2.

Table 1. Techical data MT NOLOWATI III

Type	**Semi-hermetic type multi cylinder**
Maker	Mitsubishi Electric corporation
Max pressure	10.0 Kg/cm2
Normal pressure	2.00 – 4.00 Kg/cm2
Defristing Source	Electric
Cooling Capacity	2850 kcal/H(CT 40 C/ET-23 C
Oil Separator	M301404
Refrigrant	R-22

Table 2. Measured Operating Parameters (Before and After Repair)

Paramater	**Condition Before**	**Condition After Repair**
Meat Compartment Temp.	+2°C (Suboptimal)	-12°C (Normal)
Vegetable Compartment Temp.	+14°C (Suboptimal)	+6°C (Normal)
Suction Pressure	< 1.50 Kg/cm^2 (Unstable)	3.20 Kg/cm^2 (Normal)
Condenser Condition	Heavily Clogged / High Temp	Clean / Normal Heat Transfer
Evaporator Status	Severe Frost Buildup	Clear / Normal Airflow

4.2 Interview

Based on an interview with the Chief Engineer of MT Nolowati III, the suboptimal performance of the provision refrigeration system is primarily attributed to technical failures such as refrigerant leaks, malfunctioning thermostats, and the accumulation of debris on critical components. A significant emphasis was placed on the condenser; when this component becomes clogged or dirty, it fails to effectively reject heat, preventing the system from reaching the desired low temperatures. Furthermore, the engineer identified operational stressors as contributing factors, specifically the neglect of routine maintenance, high ambient temperatures in the machinery space, and the overloading of storage compartments, which places excessive strain on the cooling unit.

To address these issues and determine the condition of the machinery, the Chief Engineer outlined practical diagnostic methods and preventive strategies. Assessment techniques include verifying that the condenser outlet pipe is warm—indicating normal heat transfer—as well as visually inspecting for dust buildup and monitoring fan operation for irregularities. To prevent damage and ensure sustained efficiency, the engineer recommended a strict regimen of routine maintenance that focuses on cleaning the condenser to maintain airflow, checking for leaks, verifying thermostat accuracy, and managing storage loads to avoid exceeding the system's capacity.

4.3 Documentation

To substantiate the findings from earlier surveys and interviews, a documentation study was conducted to provide physical evidence based on primary data collected during the author's sea service on the MT Nolowati III. The analysis revealed that the condenser grilles were heavily obstructed by accumulated clumps of dirt, a condition that underscores the critical need for rigorous and routine inspections of the machinery to prevent recurrence. The specific results of this documentation review are detailed as follows:

Figure 1. Clogged Condenser

Figure 2. Condenser Cleaning Process

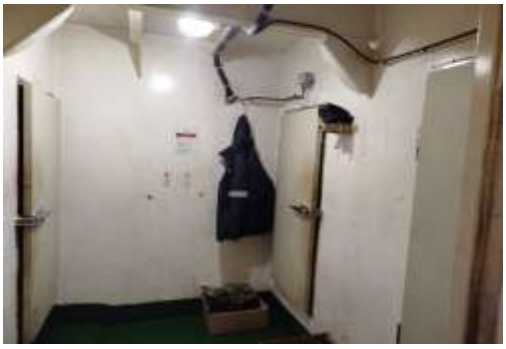

Figure 3. Refrigerant Room

Figure 4. Condensor Fan

4.4 Root-Cause Analysis

Through triangulation of the physical inspections and interview data, the RCA identified that the primary driver of system inefficiency was not a refrigerant leak, but rather a severely clogged condenser. The accumulation of clumps of dirt on the condenser grilles acted as an insulator, drastically reducing heat transfer. According to thermodynamic principles, this obstruction forces the condensing pressure and temperature to rise, which overloads the compressor and decreases the net refrigeration effect.

Additionally, thermostat malfunctions and a frozen evaporator were identified as secondary basic events in the FTA. The failed defrost system allowed ice buildup, which choked the airflow across the evaporator coils, further eliminating the system's ability to absorb heat from the storage room.

4.5 Corrective Actions

Immediate corrective maintenance involved a comprehensive overhaul of the cooling unit. The technical team executed mechanical cleaning of the condenser to remove the physical obstructions, restoring unobstructed airflow. Simultaneously, the thermostat was recalibrated, and the malfunctioning condenser fans were repaired. These interventions successfully stabilized the thermodynamic cycle, returning the suction pressure to 3.20 Kg/cm² and lowering the room temperatures to their required set points.

4.6 Preventive Maintenance Implications

To prevent recurrence, the discussion highlights the necessity of structured preventive maintenance. Monitoring diagnostic indicators—such as the condenser outlet pipe temperature and fan acoustics—is critical. Furthermore, environmental stressors, specifically poor ventilation in the machinery space, must be mitigated to reduce thermal strain on the compressor.

5. Conclusion

Field The performance degradation of the refrigeration system on the MT Nolowati III, which threatened provision safety, was primarily caused by technical and maintenance failures rather than chemical leaks. The diagnostic analysis confirmed that a severely clogged condenser, exacerbated by thermostat and fan malfunctions, restricted thermodynamic heat transfer and overloaded the compressor.

To ensure sustained operational reliability, it is highly recommended that marine engineers implement a rigorous, condition-based inspection schedule focusing on routine condenser cleaning and defrost timer calibration. Furthermore, all maintenance activities must strictly align with the manufacturer's operational parameters to prevent the cascading failure of auxiliary maritime equipment.

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