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Optimizing The Implementation of Tank Cooling down to Prepare for The LNG Loading Process on LNG Carrier Pan Africa Ships

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ABSTRACT

The tank coolingdown process is a critical stage in LNG cargo operations to prevent thermal shock and ensure containment integrity. This study aims to optimize the coolingdown operation on the LNG/C Pan Africa by analyzing technical deviations and operational failures using a production management and safety risk framework. Employing a descriptive qualitative method, data were collected through field observations, in-depth interviews with deck and engine officers, and validated via data triangulation. The findings indicate that while general procedures complied with SIGTTO standards, significant deviations hampered efficiency: (1) A cooldown valve leakage due to corrosion reduced the cooling rate from the standard 20°C/hour to approximately 10°C/hour, significantly extending the operational cycle time; (2) A 1.5-hour delay in the nitrogen system activation prevented the Inter-Barrier Space (IBS) pressure from reaching the required safety threshold of 0.2–0.4 kPa. The study concludes that these failures stem from weaknesses in the Preventive Maintenance (PM) system and inter-departmental coordination. Optimization strategies proposed include the implementation of pre-arrival valve function tests and Joint Readiness Check protocols to minimize downtime and ensure process safety control.

1. Introduction

Liquefied Natural Gas (LNG) plays a vital role in the global energy supply chain, where marine transport efficiency and safety are paramount. In LNG carrier operations, the *tank cooling down* phase is crucial for gradually lowering tank temperatures from ambient to cryogenic levels (-130°C) to avoid thermal stress on the membrane structure (Hisham, 2013). Industry standards such as the IGC Code and SIGTTO establish strict parameters for this process.

LNG is defined as a cryogenic liquid formed from a mixture of natural hydrocarbon molecules, primarily consisting of 65% to 100% methane and up to 16% ethane, with the remainder comprising propane, butane, pentane, nitrogen, and carbon dioxide (Hisham, 2013). As a cryogenic substance similar to liquid hydrogen or helium, LNG remains liquid at roughly -162°C under atmospheric pressure and begins to vaporize at temperatures above -160°C (Russel, 2024). The liquefaction process is critical for logistics because changing the gas into a liquid state reduces its volume by approximately 600 times per metric ton, making it highly efficient for storage and shipment.

The loading of LNG onto gas tankers is a complex operation requiring precise planning by deck officers to ensure safety (Mudiyanto, 2018; Arso Martopo, 2004), specifically through a critical preparation phase known as "Tank Cooling down" designed to prevent thermal shock when -160°C cargo enters the tanks. This process typically spans 10 hours, gradually lowering tank temperatures from around -30°C to a target of -130°C using either retained onboard cargo or shore-supplied LNG, during which High Duty (HD) compressors return resulting vapors to the terminal (Yeo, 2009). The cooling phase is vital for allowing tank materials to acclimate to extreme thermal changes and for regulating pressure within the Insulation Space (IS) and Inter Barrier Space (IBS), all of which are closely monitored via indicators in the Cargo Control Room.

During the tank cooling process, significant vaporization occurs when the Liquefied Natural Gas (LNG) contacts the relatively warmer tank surfaces. While the resulting vapor can be utilized as ship fuel or returned to shore via High Duty (HD) Compressors, excessive vapor accumulation leads to dangerous pressure increases that threaten structural integrity, create

fire hazards (Reports, 2019), and cause operational delays. Consequently, the loading operation is strictly prohibited from commencing until the tanks achieve the required temperature of -130°C to ensure safety and efficiency. Research conducted on board the LNG/C Pan Africa revealed a specific failure in this procedure on September 25, 2024, where a cooldown valve leak went undetected (McLennan, 2015) due to a lack of re-inspection by the crew, causing a significantly delayed temperature drop. This incident underscores the critical necessity for officers and crew to actively adhere to established Standard Operating Procedures (SOPs) regarding observation and equipment checks (Siti Mariyah, 2021). Accordingly, this study aims to examine the execution of the tank cooling process on the LNG/C Pan Africa and identify the specific factors contributing to suboptimal cooling performance.

However, a significant gap often exists between ideal procedures and actual field execution. Research conducted on the LNG/C Pan Africa identified operational anomalies where efficiency targets were missed due to undetected support equipment failures. Recent international literature, such as Piasecki et al. (2021) and Abdelmalek & Soares (2024), emphasizes that LNG operational reliability depends not only on procedural compliance but also on dynamic risk management and human reliability. The delayed detection of valve leakage and nitrogen system unreadiness indicates a failure in the preventive maintenance system, directly impacting process safety and port turnaround time.

Therefore, this study aims to:

1. Analyze the root causes of the reduced cooling rate and IBS pressure failure during the coolingdown operation.
2. Evaluate the impact of these technical deviations on production performance (operational time) and safety envelopes.
3. Formulate optimization strategies based on maintenance management and process control principles to prevent recurrence.

2. Literature Riview

2.1 Optimalization

To provide a theoretical basis for the study on optimizing tank cooling down operations aboard the *LNG/C Pan Africa*, it is necessary to define the core concept of optimization.

According to the *Kamus Besar Bahasa Indonesia*, optimization is derived from the term "optimal," signifying the highest or best standard, and refers to the extent to which requirements are met through specific activities (Indonesia, K. B., 2016). Furthermore, Winardi (2006) describes optimization as a measure that ensures the achievement of desired goals, essentially representing the pursuit of the most favorable outcome or value available within a given context.

2.2 Tank Cooldown

The tank cooldown process is a critical safety operation that must be executed gradually to prevent thermal shock and structural damage to the cargo containment system. As emphasized by SIGTTO, controlled cooling limits vapor generation and protects tank materials from sudden stress caused by extreme temperature shifts. This procedure generally involves spraying LNG from the terminal into the tanks, where the resulting vapor is returned to the shore facility using the ship's High Duty (HD) Compressors (Yeo, 2009). Throughout this operation, strict monitoring of nitrogen pressure within the insulation and inter-barrier spaces is essential to compensate for contraction, requiring significant output from the ship's nitrogen generators. While specific durations vary by vessel design—typically 10 to 12 hours for membrane-type carriers versus 24 to 36 hours for Moss-type carriers—the industry standard for a tank to be considered ready for loading is achieving an average temperature of approximately -130°C (Hisham, 2013).

Operational execution follows a rigorous sequence of preparatory and procedural steps to ensure system integrity. This begins with logistical arrangements such as safety meetings, the connection of communication cables, and the rigging of the Emergency Shutdown (ESD) system. Once the loading arms are connected, they undergo nitrogen purging to eliminate oxygen and leak testing to verify seal tightness before the cooling medium is introduced. During the active cooling phase, crew members must manage valve alignments to maintain specific cooling rates—typically 20°C per hour initially—and regulate tank pressures. The process is formalized through "Initial Gauging," where the Chief Officer records baseline data on liquid levels, temperature, and pressure via the Custody Transfer Measurement System

(CTMS), ensuring the vessel is fully prepared to receive the bulk cargo safely (Mudiyanto, 2018; Arso Martopo, 2004)..

2.3 Cargo Loading

Cargo loading is a systematic operation that prioritizes vessel stability, balance, and structural safety (House, 2007), utilizing a complex array of specialized equipment to handle liquid operations effectively. The cargo is contained within tanks designed to ensure structural integrity and prevent contamination (Yılmaz, 2016), with the actual transfer of fluids between the ship and the terminal facilitated by Loading Arms (Firdaus, 2011). To manage the critical temperature requirements of operations, Cooldown Valves are employed to regulate cooling rates and maintain system integrity (McLennan, 2015), while Spray Rails and Spray Pumps are utilized to distribute high-pressure liquids for cooling, cleaning, and protection against external elements (Yeo, 2009; Tuan, 2015). Furthermore, the safety of the entire operation is bounded by the Loading Line, which delineates the maximum permissible draft and load limit to prevent instability during the voyage (KBBI).

2.4 Liquefied Natural Gas (LNG)

Liquefied Natural Gas (LNG) is natural gas that has been converted into a liquid state through cryogenic cooling to approximately -162°C , a process that significantly enhances logistical efficiency by reducing the gas's volume by 600 times (Hisham, 2013). This transformation allows for the transport of energy to regions lacking pipeline infrastructure using specialized LNG carriers equipped with heavily insulated storage tanks designed to maintain the cargo's low temperature during transit. These vessels are essential components of the global energy supply chain, enabling the safe distribution of clean, environmentally friendly fuel from export facilities to import terminals across the world.

3. Research Methodology

This research utilizes a descriptive qualitative approach to investigate operational conditions in depth.

3.1 Safety Indicators and Operational Variables

The observation focused on key parameters

determining cooldown success:

- a. Cooling Rate: Standard temperature deviation per hour (Target: 20–30°C/hour).
- b. Barrier Pressure (IBS): Pressure stability in the inter-barrier space (Target: 0.2–0.4 kPa).
- c. Equipment Integrity: Physical condition of cooldown valves and Nitrogen Generator readiness.

3.2 Participants and Informants

Primary data were obtained through purposive sampling involving key personnel responsible for cargo operations:

- a. Chief Officer: Responsible for cargo planning.
- b. Cargo Engineer: Responsible for technical aspects and cargo equipment maintenance.
- c. Third Officer: Tasked with monitoring the Integrated Automation System (IAS) in the Cargo Control Room.
- d. Able Seaman: Executor of physical inspections and manifold safety rounds.

3.3 Data Validation Techniques

Data validity was tested using source and technique triangulation. Field observation data (e.g., valve leakage) were cross-referenced with historical data from the *Cargo Logbook* and temperature graphs from the IAS, and further deepened through interviews to ensure accurate root cause analysis.

4 Results and Discussion

4.1 Observation and Incident Analysis

Based on observations conducted aboard the MV. Pan Africa during a seven-month sea service tenure, specifically on voyage number 7 starting September 18, 2024, the vessel prepared for LNG loading at Zhuhai Terminal, China. The operation began with a retained heel cargo of approximately 1000 m³ in tank number 4, utilized both as fuel—given the ship's tri-fuel capability (Diesel Oil, Dual Fuel, and Boil-Off Gas)—and to maintain a cryogenic baseline to expedite the cooling process. Following the Ship Shore Safety Checklist (SSSCL) meeting in accordance with ISGOTT and IGC Code regulations, the terminal and vessel executed a rigorous connection sequence. This included rigging the gangway, connecting Emergency Shutdown (ESD) and communication cables,

and attaching loading arms (Nos. 2, 3, 4, and vapor arm), followed by nitrogen purging to reduce oxygen content below 1% and leak testing at 5 bar pressure (Sugiyono, 2018). Once the "Initial Gauging" via the Custody Transfer Measuring System (CTMS) and ESD Cold Test were completed, LNG was introduced through the spray rails to gradually cool the tanks, with vapors returned to shore via HD Compressors to manage internal pressure.



Figure 1. Loading arm and manifold installation activities

However, the cooling operation encountered a significant deviation on September 25, 2024. While the initial hour proceeded normally with a temperature drop from 40°C to 30°C, the cooling rate subsequently decelerated drastically, dropping only 10°C in the following hour. An Able Seaman on safety rounds discovered a leak in the cooldown valve at loading arm manifold No. 2. The Third Officer, alerted by the seaman and an alarm on the Integrated Automatic System (IAS) indicating a flow rate drop, immediately suspended operations (McLennan, 2015). The Cargo Engineer identified the root cause as a valve that failed to seal tightly due to a corroded handle. Consequently, operations resumed with loading line No. 2 isolated to prevent further leakage, though this incident highlighted a critical failure in pre-operational equipment verification.



Figure 2. Loading arm and manifold installation activities

A secondary operational inefficiency was identified regarding the nitrogen system preparation. Contrary to the company's standard procedures requiring stable pressure in the cofferdam and insulation spaces prior to cooling, the nitrogen pressure in the inter-barrier space had not reached the minimum required 0.4–0.6 kPa threshold because the nitrogen generator was not activated early enough (Yeo, 2009). This oversight caused a 1.5-hour delay in stabilizing the insulation space, risking thermal imbalances. These incidents—the valve leak and the delayed nitrogen system activation—collectively hindered the vessel from achieving the target -130°C tank temperature within the standard 10-12 hour window, underscoring a lack of effective coordination between the deck officers and the gas engineer during the preparation phase..



Figure 3. Leak in the cooldown valve

4.2 Interview Analysis

To validate the observational data, direct interviews were conducted with key personnel involved in the tank cooling operations aboard the *LNG/C Pan Africa*. The Chief Officer confirmed that while the operation was

meticulously planned according to the Cargo Loading Plan and governed by strict standards such as the Ship Shore Safety Checklist (SSSCL), ISGOTT, and the IGC Code, mechanical failures ultimately disrupted the schedule. He acknowledged that the leak in the cooldown valve on loading line number 2 forced a temporary suspension of operations. After consulting with the terminal, the decision was made to isolate the faulty line and proceed, reinforcing that operational safety takes precedence over logistical efficiency (Mudiyanto, 2018).

The Cargo Engineer provided a technical analysis of the failures, attributing the valve leakage to corrosion on the handle that prevented a complete seal—a clear indication of inadequate maintenance on infrequently utilized equipment. Furthermore, he highlighted a critical coordination failure regarding the nitrogen system; the nitrogen generator was not activated in time, resulting in the Inter-Barrier Space (IBS) pressure failing to reach the required minimum of 0.2–0.4 kPa. This oversight, caused by miscommunication between the watch officer and the engineering team, compromised the temperature stability of the insulation space and underscored the necessity for stricter adherence to Standard Operating Procedures (SOPs) regarding equipment readiness (Yeo, 2009; Tuan, 2015).

From the perspective of monitoring and control, the Third Officer detailed the sequence of detection from the Cargo Control Room (CCR). Tasked with watching the Integrated Automation System (IAS), he observed an alarm indicating a significant drop in the cooling rate. Upon receiving a visual confirmation from the deck crew and verifying the situation via CCTV monitoring, he immediately coordinated with the terminal to halt the LNG flow. His testimony highlights the critical importance of situational awareness and rapid communication in mitigating risks during high-pressure cargo operations (House, 2007).

Complementing the electronic monitoring, the Able Seaman described the physical detection of the hazard during routine safety rounds recorded in the cargo logbook. He visually identified LNG dripping from the connection at loading arm number 2 and promptly reported the anomaly to the CCR, a decisive action that prevented the escalation of the incident (Reports, 2019). While

acknowledging the value of pre-operation briefings led by the Chief Officer, the seaman suggested that future protocols must include more rigorous physical inspections of specific valve components to prevent similar mechanical failures.

4.3 Analysis Data

Based on observations and documentation from the *LNG/C Pan Africa*, the tank cooling operations largely complied with strict regulatory frameworks, including the Cargo Manual, IGC Code, and ISGOTT (Mudiyanto, 2018). Standard preparatory measures—ranging from safety meetings and loading arm connections to purging and ESD testing—were executed according to procedure. However, the operation failed to meet efficiency targets due to specific technical and organizational deviations. A critical failure occurred on September 25, 2024, when a rusted cooldown valve handle prevented a proper seal, causing the cooling rate to plummet from 30°C/hour to 10°C/hour and extending the process well beyond the standard 10–12 hour window (McLennan, 2015). Furthermore, a 1.5-hour delay in activating the nitrogen generator prevented the Inter-Barrier Space (IBS) pressure from reaching the required 0.4–0.6 kPa threshold during the initial phase, risking thermal instability (Yeo, 2009).

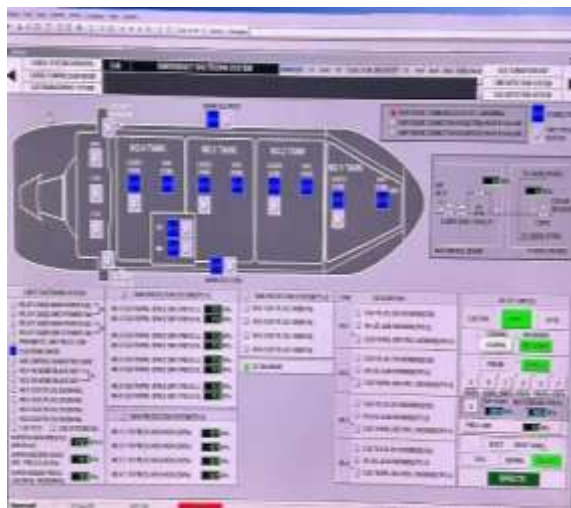


Figure 4. Implementation of Emergency Shutdown System (ESD)

Despite these technical setbacks, effective human surveillance played a decisive role in maintaining safety. The Able Seaman's visual detection of the leak during routine safety rounds, combined with the Third Officer's

continuous monitoring of the Integrated Automation System (IAS) in the Cargo Control Room, allowed for immediate intervention to prevent escalation (Reports, 2019). While the presence of retained "heel" cargo in tank number 4 provided a thermal advantage, the study concludes that optimization was ultimately hindered by the inadequate maintenance of infrequently used equipment and a lapse in coordination between the deck and engine departments regarding the readiness of auxiliary support systems (Siti Mariyah, 2021).

4.4 Discussion

Production Performance and Cycle Time Analysis

Operational efficiency relies heavily on adherence to the standard cycle time. Observations revealed a drastic drop in the cooling rate from 30°C/hour in the first hour to only 10°C/hour subsequently. From a production management perspective, this 50% efficiency loss is not merely a technical issue but a production loss. This deviation extended the operation duration, increased Heel (retained cargo) consumption, and added to "waiting time" waste (Downtime) at the terminal. The root cause was identified as a failure in Preventive Maintenance (PM): corrosion on the handle of the No. 2 loading line valve prevented a proper seal—a condition that should have been detected via function tests prior to port arrival.

Risk Assessment and Process Safety

The operational deviations pose serious safety implications when analyzed using a risk matrix:

- a. **Membrane Integrity Risk:** The 1.5-hour delay in activating the Nitrogen Generator caused the IBS pressure to fail in reaching the minimum safe threshold of 0.4 kPa. Referring to Piasecki et al. (2021), pressure instability in insulation spaces during extreme temperature drops can trigger membrane deformation.
- b. **Gas Leakage Potential:** The LNG leak at the manifold, while immediately isolated, increased the risk of flammable gas exposure on deck. The partial *Emergency Shutdown* initiated by the Third Officer was the correct reactive measure, but the incident signifies a failure in the preventive barrier layers.

Human Factors and Safety Culture

The analysis indicates that human factors contributed significantly—not due to incompetence, but due to coordination gaps. The delayed nitrogen supply reflects a "silo mentality" between the Deck and Engine Departments. Abdelmalek & Soares (2024), in a review of maritime LNG risks, note that communication failures between teams are a leading cause of port incidents. On the LNG/C Pan Africa, the lack of a cross-verification protocol (Joint Readiness Check) for the nitrogen generator before commencing cooldown represents a procedural gap that must be closed.

5 Conclusion

The evaluation of tank cooldown operations on the LNG/C Pan Africa concludes that while international regulatory frameworks were generally followed, operational efficiency was compromised by specific deficiencies in maintenance management and team coordination. The cooldown valve leakage and nitrogen system delay were clear indicators of gaps in Preventive Maintenance (PM) execution.

To optimize future operations, the following strategies are recommended:

1. Strengthen Preventive Maintenance: Mandate pressure/function testing for all cargo valves and auxiliary systems (Nitrogen) 24 hours prior to arrival, shifting from visual inspection to operational testing.
2. Integrated Communication Protocols: Implement a "Joint Readiness Check" between Deck and Engine departments to ensure utilities are stable *before* the critical path of the operation begins.
3. Risk-Based Competency Enhancement: Conduct simulation drills for cooling system failures to enhance crew situational awareness regarding pressure and temperature anomalies.

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