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Article

Efforts to Increase Boil-Off Gas (BOG) Without Fuel Gas Pump in The State of Ballast Voyage at M.T. Coral Energy

Areza Putri Airlangga[1,a*], Sutoyo[2,b], Elly Kusumawati[3,c], Imam Firdaus[4,d]
[1,2,3,4] Teknologi Rekayasa Operasi Kapal (TROK), Politeknik Pelayaran (Poltekpel) Surabaya

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E-mail: [a,*]arezaputri1201@gmail.com (Corresponding author), [b]sutoyopoltekpel@gmail.com, [c]elly.kusumawati@poltekpel-sby.ac.id, [d]imam.firdaus@poltekpel-sby.ac.id

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A B S T R A C T

This study examines practical efforts to increase Boil-Off Gas (BOG) production without relying on the Fuel Gas Pump (FGP) during ballast voyage on the M.T. Coral Energy. In this condition, the vessel carries only a small amount of heel cargo, causing limited natural evaporation and a significant drop in tank pressure, which often results in insufficient BOG supply for the main engine. These operational constraints highlight the need for an alternative strategy that is both efficient and safer for cryogenic equipment.Using a qualitative descriptive approach, the research incorporates direct observation, structured interviews with deck officers, and operational documentation from the vessel. Data were analyzed using a fishbone framework to trace the root causes of low BOG production, focusing on technical, environmental, and human-factor aspects. The findings show that applying the top spray method using the deepwell pump effectively increases tank pressure and stabilizes BOG availability during ballast voyage. This method helps maintain a consistent gas supply for propulsion without adding mechanical load or maintenance risks to the FGP. The success of this approach depends largely on accurate flow control, careful pressure monitoring, and the crew's understanding of the operational procedure. Overall, the study concludes that top spray is a reliable and energy-efficient alternative for BOG management when FGP use is minimized. The results are expected to support LNG carrier operations, particularly in optimizing fuel systems under low-cargo condition.

1. Introduction

The surging global market demand has necessitated an expansion in Liquefied Natural Gas (LNG) transportation, prompting companies like Anthony Veder to operate specialized vessels such as the M.T. Coral Energy. This ship transports LNG, a cleaner energy alternative characterized as a colorless, odorless, and highly flammable hydrocarbon with a boiling point of approximately -163°C (SIGGTO LGHP 2016, p. 3). To manage the natural evaporation of the cargo caused by heat ingress during transit, the vessel utilizes the resulting Boil-Off Gas (BOG) as propulsion fuel; this process is essential for maintaining optimal tank pressure and temperature, effectively handling Boil Off Rates (BORs) that typically fluctuate between 0.10% and 0.15% of the daily cargo volume depending on the insulation system's design.

During a ballast voyage in late May 2024, the vessel experienced a shortage of natural Boil-Off Gas (BOG) for fuel due to calm sea conditions and the absence of a payload while awaiting charter orders. Standard procedures dictate that when natural BOG levels are inadequate, liquid cargo should be processed through a fuel gas pump and a forcing vaporizer to supplement the fuel supply (SIGGTO LGHP 2016, pp. 135-136). However, to mitigate the high maintenance costs associated with the fuel gas pump, an alternative method was employed using the deepwell pump. This technique involves transferring liquefied gas between tanks via the top spray line to stimulate evaporation and artificially increase BOG production.

Driven by the need to optimize this alternative process, this study is titled "Efforts to Increase Boil-Off Gas (BOG) Without Fuel Gas Pump in Ballast Voyage at M.T. Coral Energy." The research aims to achieve two primary objectives: first, to analyze the variations in BOG production specifically during ballast voyages, and second, to identify effective methods for enhancing BOG generation without relying on the fuel gas pump, thereby ensuring operational efficiency.

Existing literature extensively discusses BOG management during laden voyages, yet operational strategies for ballast voyages remain underexplored. Specifically, reliance on the Fuel Gas Pump (FGP) during these low-cargo conditions poses significant limitations, including high maintenance costs and mechanical risks due to unstable cooling cycles. Addressing this gap, this study focuses on a non-FGP strategy. It positions itself to validate the effectiveness of the 'top spray' method using deep well pumps as a safer, energy-efficient alternative for maintaining BOG production on the M.T. Coral Energy.

2. Literature Riview

2.1 Boil-Off Gas (BOG)

Boil-Off Gas (BOG) is defined as the vapor generated when cryogenic liquids, such as liquid hydrogen or LNG, undergo evaporation during storage and transport due to heat ingress from the surrounding environment (Jessie R. 2022; T. Wlodek 2020). Despite the use of high-quality insulation, the significant temperature disparity between the cargo, maintained at approximately -162°C, and atmospheric conditions leads to unavoidable evaporation rates of 0.1% to 0.15% daily, which raises internal tank pressure (SIGGTO LGHP 2016, p. 142). To manage this pressure accumulation and ensure supply chain safety, industry standards dictate that BOG should be utilized for propulsion or reliquefaction; consequently, any excess gas not used for fuel must be safely incinerated in the Gas Combustion Unit (GCU) to prevent direct release into the atmosphere.

2.2 Production Change

Changes in Boil-Off Gas (BOG) production are a critical factor in the LNG industry, significantly influencing both operational efficiency and environmental sustainability (Zhang et al, 2021). These fluctuations are driven by a combination of physical variables—such as tank design, ambient temperature, pressure, and the specific composition of the LNG, particularly its nitrogen content—as well as the effectiveness of the management technologies employed (T. Wlodek, 2019; Kim et al. 2023). As heat ingress elevates internal tank pressure, effective BOG management becomes essential; this requires optimizing recovery processes to utilize the gas as propulsion fuel, thereby enhancing energy efficiency, while safely combusting any excess in a Gas Combustion Unit (GCU) to prevent atmospheric release (Pavitra Sandilya, 2022).

However, in the specific context of ballast voyages, these fluctuations are exacerbated by the minimal volume of 'heel' cargo. The reduced liquid mass limits natural sloshing effects—which typically aid evaporation—making the internal tank pressure drop significantly. Therefore, understanding production changes under these low-level conditions is vital for implementing alternative generation methods like top spraying

2.3 Fuel Gas Pump

A pump is fundamentally defined as a component designed to transfer fluids from areas of low pressure or elevation to higher ones (Rafli, Djajari, Priyanto 2024). In the context of LNG vessels, fuel gas pumps are critical for delivering fuel to engines under specific pressure requirements, necessitating designs that can withstand the unique challenges of high pressures and low temperatures (SIGGTO LGHP 2016, pp. 168, 170). These systems are generally categorized into three configurations: in-tank pumps for initial extraction, external pumps for pressure boosting, and redundancy systems to ensure operational continuity. Furthermore, depending on the propulsion needs, these pumps function as either high-pressure systems delivering approximately 300 kgf/cm² for two-stroke engines (Davydenko & Baranov, 2022), or as safer low-pressure alternatives that rely on precise process valves and feedback controllers (Milioulis et al., 2022).

Specifically regarding LNG tankers, the industry often employs the Fuel Gas Pump Cryogenic Submerged ARTIKA 160 – 2 stages, which is capable of transferring cryogenic liquids at temperatures as low as -196°C under varying flow and pressure conditions. This unit features a motor that is integral to the pump and operates completely submerged, utilizing the pumped fluid itself for lubrication; this design eliminates the need for wear-prone sealing elements and ensures the pump is always ready for immediate operation. Whether controlled via frequency inverters or regulating valves, these pumps are vital for the safe storage and distribution of volatile cryogenic liquids across receiving terminals and regasification processes.

2.4 Ballast Voyage

The operation of a ballast system involves the intake (ballasting) or discharge (deballasting) of seawater to ensure a vessel's stability and structural integrity during transit and port activities (Basuki et al., 2020; Budi. P & Ratna, D.K, 2020). This process allows the crew to adjust the ship's center of gravity and draft to counter varying weather conditions and waves (SIGGTO LGHP 2016, p. 364). The primary functions of ballast water include maintaining stability and maneuverability when the ship is empty (Diasamidze & Shotadze, 2019), compensating for weight lost due to fuel and water consumption during the voyage (Kholdebarin et al., 2020), and reducing structural stress on the hull (Ibrahim & El-Naggar 2019). While essential for safety, these operations also present environmental challenges that necessitate effective management systems.

For gas carriers, ballast voyages involve the strategic management of "heels," or residual cargo retained to keep tanks cool. While LPG carriers typically use heels for reliquefaction, LNG carriers must calculate the optimal heel amount based on voyage length, fuel usage, and terminal requirements to avoid delays caused by excessive residue or insufficient cooling. According to (SIGGTO LGHP 2016, p. 365), LNG vessels operate under two main conditions: a "Warm Ballast Voyage," where tanks warm up and excess pressure is managed via the Gas Combustion Unit (GCU), and a "Cold Ballast Voyage." The latter utilizes spray pumps to maintain low temperatures, offering significant advantages such as faster turnaround times, the elimination of pre-loading cooling requirements, and the prevention of wasteful gas combustion

2.5 Fishbone Analysis

According to Holifahtus Sakdiyah et al. (2022), this technique is highly effective in management decision-making contexts, as it enables teams to accurately diagnose root causes by structurally mapping contributing factors across key categories such as Man, Method, Machine, Material, and Environment.

3. Research Methodology

This research employs a qualitative descriptive methodology to produce comprehensive descriptive data based on the observed behaviors and statements of the subjects (Bogdan and Taylor in Moloeng, 2007:4). A qualitative approach was selected to gain an in-depth understanding of the operational behavior and crew decision-making processes that cannot be captured solely by quantitative metrics. Fieldwork was conducted aboard the M.T. Coral Energy, operated by the Dutch company Anthony, from March 18, 2024, to September 12, 2024. The study specifically targets the enhancement of Boil-Off Gas (BOG) production using top spray methods during ballast voyages. To achieve this, primary data was collected through observations, documentation, and interviews with key personnel—including the Chief, Second, and Third Officers—following established protocols to clarify research issues (Creswell, 2016: 253).

To process the findings, the author uses systematic data analysis techniques to compile field records and interviews into an understandable format (Sugiyono, 2017:244). The specific analytical tool employed is the Fishbone analysis, commonly used in quality management to identify root causes through systematic brainstorming. In this context, the Fishbone diagram is applied to examine factors causing BOG production fluctuations during ballast voyages without a fuel gas pump, thereby facilitating the development of effective improvement strategies and fostering a collaborative understanding of the operational challenges.

Data analysis involved a systematic coding process where field notes and interview transcripts were categorized into themes. Subsequently, the Fishbone Analysis was conducted through the following steps: (1) Defining the problem (low BOG production); (2) Brainstorming potential causes based on coded data; (3) Categorizing causes into Man, Method, Machine, Material, Environment, and Measurement; and (4) Identifying root causes to formulate improvement strategies.

4. Results and Discussion

The research was conducted aboard the M.T. Coral Energy, a 154.95-meter LNG vessel operated by the Rotterdam-based company Anthony Veder, which specializes in the safe transport of liquefied gases in the Scandinavian region. While the vessel relies on its cargo for fuel, a significant operational challenge arises during ballast voyages; unlike laden voyages where heat ingress naturally generates sufficient Boil-Off Gas (BOG) from the cargo kept at -163°C, the limited "heel" retained during ballast trips produces inadequate gas pressure for the main engine. Although standard procedures involve using a fuel gas pump and forcing vaporizer to convert liquid LNG into combustible gas, this method leads to high maintenance and operational costs. Consequently, this study investigates a more efficient alternative that utilizes deep well pumps and top spray mechanisms to artificially increase BOG production during ballast voyages, thereby securing a steady fuel supply without the drawbacks of the fuel gas pump system.

4.1 Observation Analysis

Field observations conducted aboard the M.T. Coral Energy between March and September 2024 revealed significant operational challenges regarding Boil-Off Gas (BOG) production during ballast voyages. During these periods, the vessel retains a minimal "heel" cargo of less than 3% of total capacity, with temperatures ranging between -153°C and -159°C. Under these conditions, the natural Boil-Off Rate (BOR) drops to a mere 0.06% to 0.08% per day—significantly lower than the 0.10% to 0.15% observed in fully loaded vessels—resulting in insufficient gas pressure to fuel the main engines. While utilizing fuel gas pumps could technically bridge this gap, doing so is disadvantageous due to high maintenance costs, potential mechanical malfunctions, and the reduced lifespan of equipment operating under such extreme cryogenic stress.

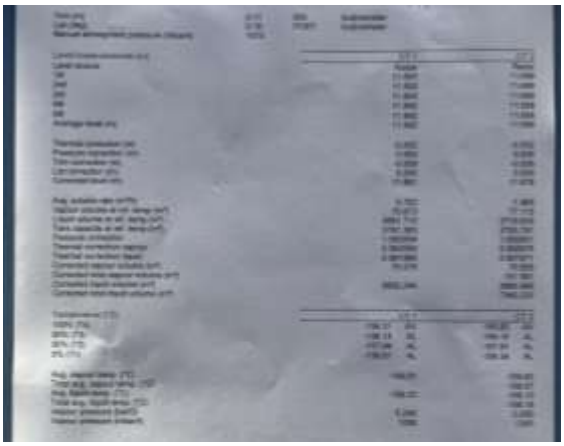

Figure 1. *Print Out Flame Screen before the use of top spray*

To resolve this fuel shortage without relying on the costly fuel gas pumps, an experimental "top spray" method was implemented using the vessel's deep well pumps. This technique circulates LNG from the bottom of the tank to the warmer upper sections, creating a temperature differential that stimulates vaporization. The experiment recorded an increase in tank pressures by approximately 0.007 barG within a single day. This data indicates a change in pressure stability following the implementation of the top spray method.

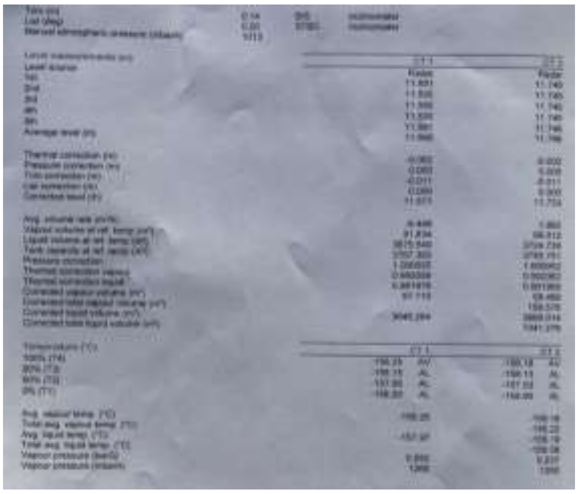

Figure 2. *Print Out Flame Screen after the use of top spray*

4.2 Interview Analysis

To validate the initial field observations, in-depth interviews were conducted with the vessel's core cargo operations team, comprising the Chief Officer, Second Officer, and Third Officer. Interviews with the deck officers revealed a strong consensus regarding operational efficiency and safety. Thematically, the respondents agreed that natural BOG generation is insufficient during ballast voyages. Regarding the method, the officers collectively identified the top spray technique as a superior alternative to the FGP due to lower energy consumption. On the aspect of safety, the consensus emphasized that strict discipline regarding flow rates is a prerequisite for the system's viability, confirming that the method is safe when standard protocols are followed.

The Second Officer provided further context regarding environmental variables, noting that calm weather and sea conditions exacerbate the issue of low BOG production by reducing the natural sloshing and convection within the tanks. When the vessel is stable, LNG evaporation rates plummet, leading to insufficient fuel gas. To mitigate this, the Second Officer confirmed that the top spray system is essential for artificially accelerating evaporation. By introducing liquid into the warmer upper sections of the tank, the system ensures that pressure remains stable and safe for shipping operations, effectively counteracting the lack of natural movement caused by calm seas.

Finally, the Third Officer focused on the operational results and safety protocols, reporting that repeated application of the top spray method successfully stabilized tank pressure without any reliance on the fuel gas pump. However, the Officer emphasized that safety is contingent upon strict discipline regarding pump flow rates and operating durations. Provided these standards are met, the method is deemed entirely safe. Ultimately, there is a consensus among all three officers that the top spray method is a practical, innovative, and viable alternative procedure for managing BOG during ballast voyages, offering a solution that enhances operational efficiency while strictly adhering to safety standards.

4.3 Documentation Analysis

Documentary analysis served to cross-verify the observational data. The review of the Ship Shore Safety Checklist (SSCL) and Material Safety Data Sheet (MSDS) confirmed that the implemented top spray procedures adhered to safety regulations. Furthermore, the Engine Log Book data corroborated the pressure increases recorded during the observation phase, validating the technical feasibility of the method.

4.4 Fishbone Analysis

In To systematically identify the root causes of declining Boil-Off Gas (BOG) production and develop a recovery strategy, the researcher employed a Fishbone (Ishikawa) analysis, categorizing factors into human, method, machine, environment, material, and measurement aspects. Regarding human factors, the analysis revealed that the crew's experience with the "top spray" system was limited. Many officers were unfamiliar with the precise adjustments needed for pump flow rates and operating durations, which hindered the system from running at maximum efficiency.

In terms of method, a significant operational gap was identified: the top spray technique had not been formally incorporated into the ship's Standard Operating Procedures. This lack of formalization led to irregular usage without the necessary calculations for timing and pressure, resulting in inconsistent BOG production.

The machine aspect highlighted technical limitations, particularly the frequent disturbances in fuel gas pumps caused by unstable cooling cycles. Additionally, the deep well pumps used for the alternative method have specific pressure limits; operating them requires extreme caution to avoid cavitation, which could permanently damage the equipment.

Physical constraints were identified in the material and environmental categories. The material factor involved the low volume of "heel" cargo, which naturally limits evaporation and necessitates artificial stimulation. Concurrently, environmental conditions such as calm seas and low air temperatures reduced the heat transfer into the tanks, causing the BOG formation process to occur much slower than anticipated.

Regarding the Measurement category, the analysis identified a lack of precise operational indicators. Specifically, the absence of real-time monitoring for critical parameters—such as specific tank pressure thresholds (barG) and flow rate deviations (liters/minute)—made it difficult to detect minor fluctuations in BOG production promptly.

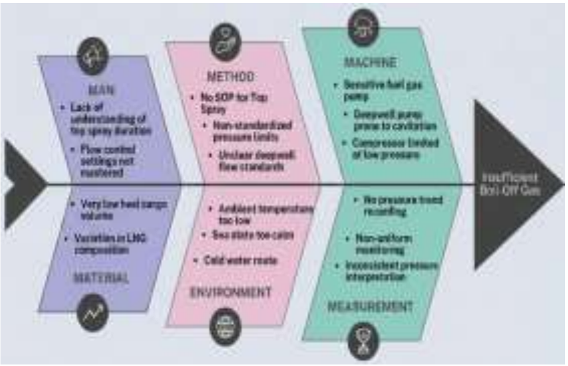

Figure 3. Fishbone Diagram

The analysis concluded that the primary drivers of low BOG production were operational inefficiencies and mechanical limitations. To address these issues, the study recommends a robust improvement strategy that includes formally standardizing the top spray procedures to ensure consistency. Furthermore, implementing real-time monitoring systems and providing targeted crew training on pump regulation and temperature management are essential steps to optimize operations and safely increase BOG production.

4.5 Discussion

The synthesis of data derived from field observations, interviews, and documentation indicates that the top spray method utilizing a deep well pump serves as a viable mechanism for enhancing Boil-Off Gas (BOG) production during ballast voyages. Empirically, the study recorded a specific tank pressure increase of 0.007 barG following the implementation of this method. This operational data demonstrates that the pressure boost was sufficient to meet the fuel supply requirements of the main engine, effectively resolving the deficit caused by the minimal volume of heel cargo.

This finding aligns with established literature on BOG management, which suggests that top spray systems are capable of modulating tank internal pressures. While previous research indicates a potential pressure increase range of 0.3 to 6.0 barG depending on spray capacity, the specific application on the M.T. Coral Energy—utilizing regulated flow rates between 6.1 and 28.0 liters/minute—allowed operators to maintain Boil-Off Rates (BOR) within a controlled range. This validates that the thermodynamic manipulation of the tank environment through liquid circulation is a reliable method for stimulating artificial evaporation without external vaporizers.

Furthermore, the Fishbone analysis underscores that the operational success of this method is contingent upon the 'Method' and 'Man' variables. The data suggests that when the top spray process is executed under rigorous pressure and temperature supervision, BOG production increases steadily without inducing risks such as overpressure or overcooling. This confirms that substituting the Fuel Gas Pump (FGP) is not merely a mechanical adjustment but requires strict adherence to standardized monitoring protocols to ensure safety.

From an operational efficiency perspective, this approach presents distinct technical advantages. By removing the reliance on the FGP, the vessel eliminates the high electrical consumption associated with the pump's operation and mitigates the mechanical wear on cryogenic components inherent to low-load cycles. Additionally, the stability of the tank pressure reduces the frequency of gas flaring in the Gas Combustion Unit (GCU), thereby optimizing cargo conservation. Consequently, the top spray method functions as an energy-efficient alternative for ensuring propulsion fuel availability during ballast voyages.

5. Conclusion

This study concludes that BOG production critically declines during ballast voyages due to minimal heel cargo and reduced tank agitation, dropping natural evaporation rates to 0.06%-0.08%. While Fuel Gas Pumps (FGP) can mitigate this, they incur high maintenance costs and risks. The implementation of the top spray method using deep well pumps proved to be a viable solution, successfully increasing tank pressure by 0.007 barG to meet main engine requirements without the drawbacks of FGP.

The Fishbone analysis identified 'Method' and 'Machine' as the dominant root causes for previous inefficiencies, primarily due to unoptimized procedures and equipment limitations. By addressing these through the top spray technique, the vessel achieved operational stability.

Based on these findings, the following recommendations are proposed:

a. Standardization: Formally incorporate the top spray method into the ship's Standard Operating Procedures (SOP), specifically for ballast voyages.
b. Training: Provide specialized technical training for the crew regarding pump flow regulation and thermodynamic monitoring.
c. Future Research: Develop mathematical models to predict Boil-Off Rates based on varying cargo compositions and environmental conditions.

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