Journal of Engineering Mechanics and Machinery (2025)
Clausius Scientific Press, Canada
DOI: 10.23977/jemm.2025.100206
ISSN 2371-9133 Vol. 10 Num. 2

Analysis of Liquefied Natural Gas Storage Tanks under Different Applications

Yaning Xu[1,a], Huixia Zhang[2,b,*], Dmytro Zhuk[3,c], Shenao Zhang[1,d], Jian Ma[2,e]

[1]*Makarov College of Marine Engineering, Jiangsu Ocean University, Lianyungang, China*
[2]*School of Ocean Engineering, Jiangsu Ocean University, Lianyungang, China*
[3]*Department of Ship Electrical Power Systems, Admiral Makarov National University of Shipbuilding, Mykolaiv, Ukraine*
[a]2024221709@jou.edu.cn, [b]hxzhang@jou.edu.cn, [c]vicedirector2012@gmail.com, [d]2024221711@jou.edu.cn, [e]2024220314@jou.edu.cn
**Corresponding author*

Keywords: *LNG storage tank, structural characteristics, application analysis*

Abstract: Liquefied natural gas (LNG) is increasingly used in marine propulsion and transport, with cargo tanks being a critical component affecting vessel safety and efficiency. Existing studies on conventional LNG carriers and LNG dual-fuel vessels have focused on typical independent tank types (A, B, and C), examining their structural characteristics, load-bearing mechanisms, and application scenarios. LNG carrier tanks are designed for large-volume, long-term storage with emphasis on low-temperature performance, fatigue resistance, and deformation control, whereas dual-fuel vessel tanks prioritize safety, compactness, and flexible arrangement for fuel supply. Current research combines theoretical analysis, numerical simulation, and regulatory comparison to evaluate tank mechanical responses and thermal behavior under low-temperature, pressure, and wave-induced loads[1]. Type C tanks, particularly the bi-lobe double-tank configuration, are highlighted for their excellent pressure resistance, insulation performance, and space utilization, making them the preferred choice for small- and medium-sized dual-fuel vessels. These studies provide important references for tank structural optimization, material selection, and safety assessment, while also offering methodological guidance for future integrated LNG fuel system design and lightweighting research.

1. Introduction

With the increasing global emphasis on environmental protection and carbon emission reduction, the shipping industry is undergoing a significant transition toward green and sustainable development. Conventional ships are mainly powered by heavy fuel oil or marine diesel engines, which emit large amounts of carbon dioxide (CO_2), sulfur oxides (SO_x), and nitrogen oxides (NO_x), posing serious threats to air quality and contributing to climate change. As a cleaner and more efficient alternative fuel, liquefied natural gas (LNG) has gained widespread attention in the maritime sector's decarbonization process. Compared with conventional marine fuels, LNG offers remarkable advantages in reducing SO_x, NO_x, and particulate matter emissions, providing shipowners with a technically mature, economically viable, and regulation-compliant solution.

Since January 1, 2020, the International Maritime Organization (IMO) has enforced the global sulfur cap regulation (IMO 2020), which limits the sulfur content in marine fuels to 0.50% m/m for ships operating outside Emission Control Areas (ECAs), down from the previous 3.50% m/m. [1]In designated Sulfur Emission Control Areas (SECAs) — including the Baltic Sea, the North Sea, the North American coast, and the United States Caribbean Sea — an even stricter limit of 0.10% m/m applies. Because sulfur is almost completely removed during the liquefaction of natural gas, LNG-powered vessels can inherently meet the 0.10% sulfur limit without complex fuel switching or additional exhaust gas treatment systems[6]. Consequently, the IMO 2020 regulation has become a strong policy driver accelerating the commercialization and adoption of LNG as a marine fuel.

2. Structure of Independent Cargo Tanks

In LNG ship applications, the design and function of cargo tanks depend on the vessel's purpose and operating conditions. In general, the cargo tanks of LNG carriers are primarily designed for large-scale loading and long-distance transportation of liquefied natural gas, whereas those on LNG dual-fuel ships serve mainly for fuel storage and gas supply. Consequently, the two types differ significantly in structural configuration, design requirements, and operational characteristics.

LNG carriers are typically equipped with large-capacity cargo tank systems that closely interact with the ship's hull structure, requiring them to simultaneously meet multiple demands such as cryogenic containment, fatigue resistance, and deformation tolerance[5]. In contrast, the fuel storage systems of LNG dual-fuel ships generally adopt independent cargo tanks, which are entirely self-supporting and structurally separate from the ship's primary load-bearing framework. Their strength and integrity are unaffected by hull deformation, providing high structural independence and safety [2,3].

According to the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)[1], independent cargo tanks are classified into three types—Type A, Type B, and Type C—based on their design pressure and geometric configuration. Among them, Type C cargo tanks, featuring excellent pressure resistance, compact structure, and flexible arrangement, are the most widely used in small- and medium-sized LNG dual-fuel ships[9,13].

2.1. Type A Independent Cargo Tank

In LNG dual-fuel-powered vessels, Type A independent cargo tanks are relatively uncommon but are still applied in certain specialized designs. This tank type typically adopts a prismatic or box-shaped configuration, belonging to the fully refrigerated, non-pressure type. It demonstrates excellent low-temperature adaptability but cannot withstand high internal pressures.

A Type A cargo tank consists of a primary barrier and a secondary barrier, with the latter often formed by part of the ship's hull structure. The materials used for these barriers must possess low-temperature resistance to prevent leakage risks. Internally, longitudinal bulkheads are generally installed to reduce liquid sloshing, thereby enhancing the operational safety and stability of the vessel.

Originally, Type A tanks were mainly used in LPG carriers, but with improvements in structure and materials, their application scope has expanded[4]. For example, the A-BOX type LNG carrier developed by China Merchants Group relocated the insulation layer from the outside of the tank to the inner side of the hull and optimized the mechanical and thermal properties of the base material. These modifications enhanced the insulation performance and structural reliability of the cargo tank, enabling it to safely contain LNG. Such developments have opened new possibilities for the use of Type A tanks in LNG fuel storage systems[4]. A cross-sectional schematic of this tank type is shown in Figure 1.

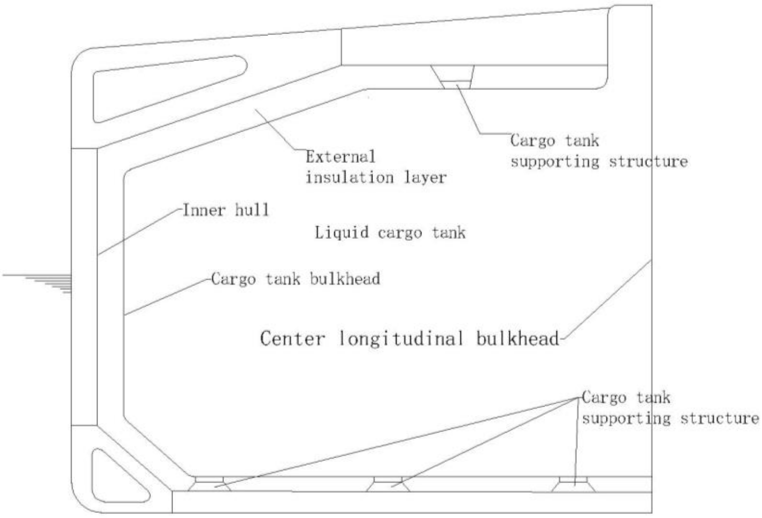

Figure 1. Schematic cross-section of a Type A independent cargo tank.

2.2. Type B Independent Cargo Tank

In LNG-fueled vessels, the B-type independent cargo tank is designed as a semi-pressurized, fully refrigerated containment system. It offers a balance between the non-pressurized A-type and the fully pressurized C-type tanks. The B-type tank features a spherical or prismatic structure, typically equipped with a primary barrier and a partial secondary barrier to ensure safety in case of leakage.

Structurally, the B-type tank is characterized by its enhanced stress analysis and fatigue evaluation, which are required to determine its stress levels, fatigue life, and crack propagation behavior according to the IMO IGC Code[1,8]. This design process involves model testing and finite element analysis (FEA) to ensure the tank's reliability under cyclic loading and cryogenic conditions[4].

In LNG dual-fuel ships, the B-type tank is less commonly used than the C-type due to its complex design and high manufacturing cost. However, it provides superior thermal insulation and structural safety, making it suitable for medium-scale LNG carriers and specific dual-fuel applications where both storage capacity and safety are prioritized[4].

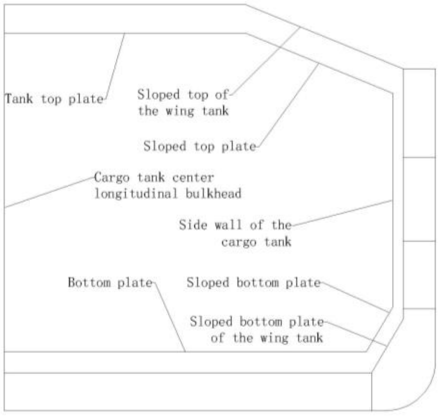

Figure 2. Cross-sectional schematic of a Type-B prismatic cargo tank.

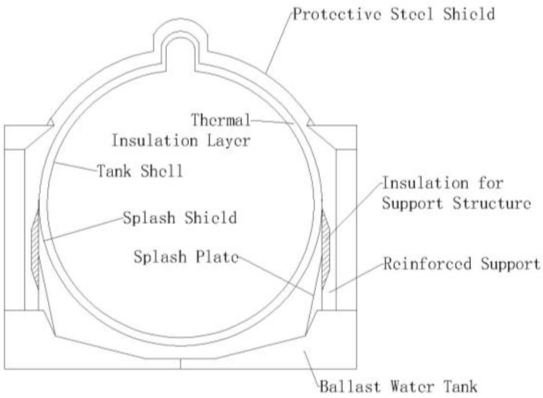

Figure 3. Cross-sectional schematic of a Type B spherical independent cargo tank.

The most representative configuration of the B-type independent tank is the MOSS-type spherical tank, widely recognized for its high safety, robust strength, and excellent resistance to thermal contraction[8]. The schematic structure of a B-type cargo tank is shown in Figure 2,3.

2.3. Type C Independent Cargo Tank

The Type C independent cargo tank belongs to the fully pressurized tank category, and its design and construction comply with pressure vessel standards[9,13]. According to differences in design pressure, structural configuration, and installation arrangement, Type C tanks can be divided into single-C, double-C, and triple-C structures This type of tank is typically supported by saddle foundations to ensure uniform load distribution and structural stability[15].Unlike Type A and B tanks, the Type C tank does not require a secondary barrier, as its integrity is entirely maintained by the pressure-resistant shell itself[9].

The design pressure of a Type C tank generally does not exceed 2.16 MPa, and it can operate under either fully refrigerated or semi-refrigerated conditions, offering excellent pressure resistance and thermal insulation[13,14]. Based on insulation methods, Type C tanks can be classified into two categories: double-walled vacuum-insulated tanks and single-walled pressure tanks with external insulation.

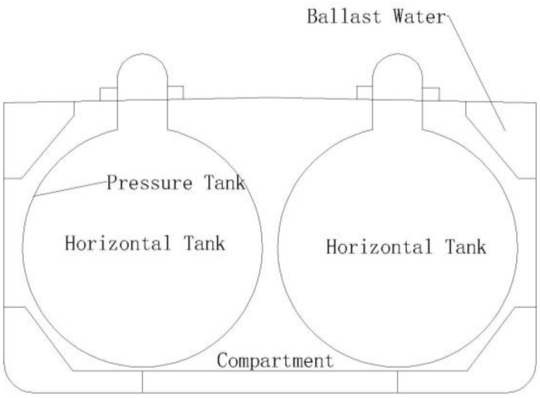

Figure 4. C-type twin cylindrical liquid cargo tank.

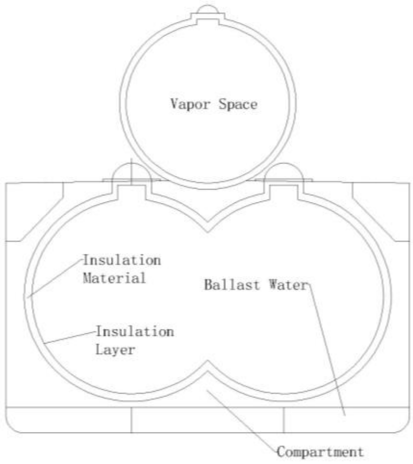

Figure 5. C-type twin-compartment cylindrical liquid cargo tank.

Among them, the single-C tank adopts a single cylindrical structure, featuring simple manufacturing and low cost but relatively low space utilization, thus it is less commonly used. The triple-C tank, composed of three intersecting cylinders, can further improve internal volume efficiency but is structurally complex and costly, and therefore used mainly in specialized vessels[13]. In contrast, the double-C (bi-lobe) tank combines high space efficiency, favorable stress distribution, and mature fabrication technology, making it the most widely used Type C tank configuration in current LNG dual-fuel vessels[7,16].The cross-sectional schematics of Type C independent cargo tanks are shown in Figures 4 and 5.

3. Comparative Analysis of LNG Carriers and LNG Dual-Fuel Vessels

Although both LNG carriers and LNG dual-fuel vessels utilize liquefied natural gas as a cryogenic medium, they differ significantly in functional orientation, system design, and operational characteristics. LNG carriers are primarily designed for large-scale transoceanic transportation, with cargo tanks emphasizing high capacity and long-term cryogenic retention performance. In contrast, LNG dual-fuel vessels use LNG mainly as a clean fuel source, with tank systems that place greater emphasis on safety, layout flexibility, and system integration.

Structurally, LNG carriers commonly adopt membrane-type cargo containment systems (e.g., GTT NO96, MARK III) or Type B independent tanks (MOSS spherical tanks), which provide large storage capacities but relatively low pressure resistance. LNG dual-fuel vessels, on the other hand, typically employ Type C independent tanks that exhibit excellent pressure endurance and wave load resistance, making them suitable for medium- and small-sized ships[8]. As Type C tanks are structurally independent of the ship's hull, they offer enhanced flexibility in spatial arrangement, inspection, and safety protection[16].

From an operational perspective, LNG carriers are designed for long voyages and large cargo volumes, requiring stable cryogenic conditions and efficient boil-off gas (BOG) recovery systems. LNG dual-fuel vessels, by contrast, operate on shorter cycles and place greater emphasis on start-up convenience, shutdown flexibility, and the safety of the fuel gas supply system[6,12].

To provide a more intuitive comparison of the cargo containment systems and corresponding research focuses of the two vessel types, Table 1 presents a systematic comparison of their key characteristics.

Table 1. Comparison of cargo tank systems of LNG carriers and dual-fuel ships.

Comparison Dimension	LNG Carriers	LNG Dual-Fuel Vessels
Functional Role	Large-scale LNG transportation for long voyages	Fuel storage for main and auxiliary engines
Main application types of cargo tanks	Membrane or Type B independent tanks	Type C independent tanks (single-, double-, or triple-C)
Design Focus	Large capacity, thermal insulation, and structural integrity	Pressure resistance, safety, and system integration
Operational Characteristics	Long voyage, stable cryogenic environment, and BOG recovery	Short voyage, flexible startup/shutdown, and tank pressure control
Structural Features	Integrated with the ship's hull	Structurally independent from the hull
Research Focus	Fatigue strength and insulation optimization	Pressure control and fuel system safety
Development Trend	Intelligent monitoring and energy-efficient design	Modular configuration and intelligent fuel management

3.1. Summary of Design Characteristics and Research Methods

This chapter reviews the design characteristics and research methodologies of LNG carriers and LNG dual-fuel ship cargo containment systems. The objective is to systematically compare the differences between the two ship types in terms of structural configuration, material properties, thermal performance, and system integration, while summarizing the main technical approaches and analytical methods adopted in existing studies.

3.2. Structural Configuration and Mechanical Performance

LNG carriers typically employ independent Type A or Type B cargo tanks, which are characterized by large capacity and low design pressure—well-suited for long-distance, large-scale LNG transportation.

In contrast, LNG dual-fuel ships commonly utilize independent Type C cargo tanks that meet pressure vessel standards, providing higher pressure resistance and superior load-bearing capacity[13].

Studies indicate that cargo tank design must comprehensively account for complex operating conditions such as hydrostatic pressure, wave loads, hull deformation, and liquid sloshing[14]. The finite element method (FEM) is widely used to analyze stress distribution and fatigue life under multi-load coupling conditions, ensuring structural safety and stability.

3.3. Material Properties and Cryogenic Performance

Cargo tank materials must exhibit excellent cryogenic toughness and crack resistance. LNG carriers generally employ 9% nickel steel or austenitic stainless steel to withstand the extremely low temperature of −163 °C, whereas dual-fuel ship tanks often use aluminum alloys or stainless-steel composites to balance high-pressure capability with maintainability[13].Research methods mainly include material property testing, low-temperature impact and fatigue tests, weld joint reliability evaluation, and microstructural analysis. Recent research trends emphasize the development of lightweight, high-toughness, and cryogenic-resistant composite materials to enhance the overall performance of LNG cargo tanks[14].

3.4. Liquid Sloshing and Thermal Performance

Liquid sloshing is a key factor affecting the structural safety and operational stability of LNG cargo tanks. Due to their larger tank volume, LNG carriers experience more pronounced sloshing effects, leading to stress concentration and fatigue damage. In contrast, the smaller and stiffer Type C or dual-cylinder tanks used in dual-fuel ships exhibit weaker sloshing behavior but may experience localized pressure fluctuations[16].

Typical research approaches include computational fluid dynamics (CFD) simulation, fluid–structure interaction analysis, and full-scale sloshing monitoring. The main focus lies in optimizing tank geometry and anti-sloshing structures to mitigate localized loads and improve thermal stability under wave-induced conditions[10,14].Thermal simulations are further employed to analyze temperature distribution and heat transfer mechanisms within the tank, providing a theoretical basis for insulation optimization.

3.5. Insulation Performance and BOG Management Systems

The insulation performance of LNG cargo tanks directly affects LNG evaporation rates and energy losses. LNG carriers generally adopt multilayer composite or double-wall vacuum insulation structures equipped with boil-off gas (BOG) recovery and reliquefaction systems, ensuring transportation efficiency and storage stability during long voyages. Dual-fuel ships, on the other hand, emphasize compact and high-efficiency insulation designs while simplifying BOG management systems to achieve rapid fuel supply response and operational flexibility. Research methods include thermal performance testing, heat transfer modeling, and evaporation loss analysis. Recent studies increasingly focus on integrated thermal management and energy recovery optimization to improve overall system efficiency[6,14].

3.6. Tank Arrangement and System Integration

Cargo tank arrangement significantly influences a ship’s stability, safety, and space utilization. LNG carrier tanks are typically arranged within the main hull framework to achieve a low center of gravity and maximize cargo capacity. Dual-fuel ships tend to adopt modular or deck-mounted configurations to improve flexibility and ease of maintenance[12].System integration research mainly focuses on coordinated design among cargo tanks, fuel supply systems, ventilation systems, and monitoring subsystems. Methods include multi-parameter design analysis, layout optimization, and system coupling simulation, aiming to enhance overall safety and operational efficiency[11,16].

3.7. Research Methods and Optimization Strategies

Studies on LNG cargo containment systems commonly combine theoretical analysis, simulation modeling, and engineering validation.

(1) Standards and regulatory comparison—based on the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) and classification society requirements[2,3]—to clarify design constraints and boundary conditions.

(2) Finite element and CFD simulations[14]—to evaluate structural strength, sloshing response, and thermal behavior.

(3) Operational data verification[10]—to validate simulation reliability using full-scale monitoring data.

The research methods and optimization strategies are summarized in Table 2.

Table 2. Summary of research methods and optimization strategies.

Research Focus	LNG Carrier	LNG Dual-Fuel Ship	Typical Research Method	Primary Objective
Structural Characteristics	Type A/B independent tanks, low-pressure large capacity	Type C pressure tanks, high-pressure small capacity	FEA structural simulation	Improve structural strength and fatigue life
Liquid Sloshing	Significant sloshing, fatigue concern	Mild sloshing, focus on local stresses	CFD simulation, coupled analysis	Optimize anti-sloshing design
Thermal Performance & BOG Management	Composite insulation and reliquefaction system	Compact insulation, direct BOG combustion	Thermal modeling and testing	Reduce boil-off losses and energy consumption
Arrangement & System Integration	Installed within main hull framework	Deck-mounted or modular layout	System integration analysis	Optimize spatial utilization and safety
Optimization Strategy	Balance between insulation efficiency and cost	Modularization and fuel supply integration	Multi-objective optimization	Enhance overall system performance

4. Conclusions

This study summarizes the differences in structural design, material selection, thermal performance, and system integration of LNG cargo tanks in conventional LNG carriers and LNG dual-fuel vessels. LNG carriers are optimized for large capacity, low design pressure, and high insulation for long-haul transport, while dual-fuel vessels emphasize pressure resistance, safety, and flexible tank arrangement for medium- and short-range operations. These distinctions reflect their respective functional requirements and engineering design strategies[6].

Finite element and computational fluid dynamics analyses, combined with engineering data and model validation[8,14], provide reliable tools for assessing tank integrity, sloshing effects, and thermal behavior. Multi-objective optimization further supports the comprehensive design of tanks with balanced safety, economy, and system integration.

Looking forward, the evolution of green shipping and intelligent vessels will drive LNG tank development toward lightweight structures, high-efficiency insulation, and smart monitoring. Advanced composite materials, intelligent boil-off gas management[6,14], and predictive health monitoring are expected to play key roles in enhancing the operational performance and safety of both vessel types.

References

[1] International Maritime Organization (IMO). International Code for the Construction and Equipment of Ships

Carrying Liquefied Gases in Bulk (IGC Code). London: IMO, 2016.
[2] DNV. Rules for Classification: Ships – Part 5 Chapter 7 Liquefied Gas Tankers. DNV AS, 2021.
[3] ABS. Guide for LNG Fuel Ready Vessels. American Bureau of Shipping, 2020.
[4] Liu, J., Feng, G., Wang, J., Wu, T., Xu, C. & Yang, K. (2024). Research on temperature distribution in container ship with Type-B LNG fuel tank based on CFD and analytical method. Brodogradnja, 75 (3), 1-16.
[5] Tomasz Piasecki Et Al (2021). Experimental Studies of Cargo Tank Cooldown in an LNG Carrier, European Research Studies Journal Volume XXIV Issue 3 - Part 2, 886-895.
[6] Arefin, M. A., Nabi, M. N., Akram, M. W., Islam, M. T., & Chowdhury, M. W. (2020). A Review on Liquefied Natural Gas as Fuels for Dual Fuel Engines: Opportunities, Challenges and Responses. Energies, 13(22), 6127.
[7] Teguh Muttaqie, DongHo Jung, Sang-Rai Cho, & Jung Min Sohn. (2022). Direct strength evaluation of the structural strength of a 500 cbm LNG bunkering ship. Structural engineering and mechanics, 81(6), 781-790.
[8] Seo, J. H., Park, K. S., Cha, I., & Choung, J. (2023). Engineering Critical Assessement for an Independent Type-B LNG Cargo Tank. Journal of the Society of Naval Architects of Korea, 60(4), 213-221.
[9] Galić, H., Slapničar, V., & Rudan, S. (2023). Design of lng tank Type C. Machines. Technologies. Materials., 17(7), 244-254.
[10] Hwang, S. Y., Kim, K. S., Jang, H. S., & Lee, J. H. (2020). Experimental and Numerical Study of Orifice Coefficient of Cargo Tank Design of LNG Vessels. Applied Sciences, 10(19), 6667.
[11] Guo, G., Wang, R., Wang, Q., Lu, J., Wu, W., & Yang, Z. (2023). Design of LNG fuel tank arrangement for a 7000-car dual-fuel ro-ro vessel. Ship & Ocean Engineering, 52(4), 66–70.
[12] Mo, J., Li, K., & Zheng, T. (2024). Key technologies of general arrangement for 8100 TEU LNG dual-fuel container ship. Ship Design & Communications, (2), 1–7.
[13] Chen, Q. (2022). Structural design and optimization of large marine independent Type C LNG fuel tanks (Master's thesis, Xi'an Shiyou University). https://doi.org/10.27400/d.cnki.gxasc.2022.000867
[14] Bai, M. (2024). Study on thermal characteristics and sloshing suppression of Type C LNG storage tanks (Master's thesis, China University of Mining and Technology). https://doi.org/10.27623/d.cnki.gzkyu.2024.001215
[15] Li, G., Wang, R., Zhang, Z., & Ma, L. (2025). A marine Type C double-lug LNG storage tank (CN Patent No. 120466563A).
[16] Yan, H., Yuan, H., Weng, Z., & Ding, C. (2024). Analysis of LNG fuel tank arrangement scheme for a large dual-fuel container ship. Journal of Shanghai Ship and Shipping Research Institute, 47(2), 21–26.