ANALYSIS AND OPTIMIZATION OF LNG DISPENCER: TECHNOLOGICAL ASPECTS AND DESIGN CHALLENGES

ANALIZA ȘI OPTIMIZAREA DISPENCERULUI DE GAZ NATURAL LICHEFIAT: ASPECTE TEHNOLOGICE ȘI PROVOCĂRI DE PROIECTARE

Ilia BEZDENEZHNYKH[1]

Abstract: *This article examines key factors affecting the accuracy of measurements during refueling with liquefied natural gas (LNG), focusing on technological and procedural challenges. Special attention is given to the cryogenic properties of LNG, the design and insulation of pipelines, and the optimization of dispenser algorithms. The research explores methods to minimize errors caused by two-phase flow and evaporation, emphasizing advanced materials, flowmeter technologies, and automation systems. The study highlights the importance of accurate fuel accounting for reducing environmental risks, improving economic efficiency, and promoting LNG as a sustainable fuel alternative. The proposed solutions contribute to standardizing LNG refueling technologies and improving operational reliability.*

.

Keywords: LNG, measurement accuracy, cryogenic systems, dispenser optimization, refueling algorithms, fuel accounting.

Rezumat: *Acest articol examinează factorii cheie care afectează acuratețea măsurătorilor în timpul realimentării cu gaz natural lichefiat (GNL), concentrându-se pe provocările tehnologice și procedurale. O atenție deosebită este acordată proprietăților criogenice ale GNL, proiectării și izolației conductelor și optimizării algoritmilor de distribuire. Cercetarea explorează metode de minimizare a erorilor cauzate de curgerea și evaporarea în două faze, punând accent pe materiale avansate, tehnologii de debitmetru și sisteme de automatizare. Studiul subliniază importanța contabilizării corecte a combustibilului pentru reducerea riscurilor de mediu, îmbunătățirea eficienței economice și promovarea GNL ca alternativă durabilă a combustibilului. Soluțiile propuse contribuie la standardizarea tehnologiilor de realimentare cu GNL și la îmbunătățirea fiabilității operaționale.*

[1] PhD student at Ural Federal University (UrFU), Russia,
e-mail: bezdenezhnykhin@gmail.com,

Cuvinte cheie: GNL, precizie de măsurare, sisteme criogenice, optimizare dozatoare, algoritmi de realimentare, contabilitate combustibil.

1. Introduction

Liquefied natural gas (LNG) is methane cooled to below its boiling point, resulting in a volume reduction of up to 600 times. This characteristic enables LNG to occupy a significant position among modern energy resources, offering an environmentally friendly and economically advantageous alternative to traditional fuels. LNG is currently widely used as fuel for automotive, marine, and rail transport, providing considerable environmental benefits through the reduction of carbon dioxide, nitrogen oxides, and particulate emissions. However, the operation of LNG is accompanied by technical challenges due to its cryogenic properties, which require specific conditions for storage, transportation, and refueling.

One of the primary tasks in creating refueling infrastructure is to ensure high measurement accuracy during refueling. This involves stringent requirements for pipeline configuration and insulation, as well as for the algorithms governing refueling systems. In the design and operation of fuel dispensing systems, not only the cryogenic properties of LNG but also the initial condition of the dispensing equipment must be considered. Factors such as temperature fluctuations and the geometry and material of the pipelines play a crucial role in maintaining the stability and accuracy of the refueling process. For instance, inadequately sealed or insufficiently insulated pipeline systems can lead to LNG evaporation, resulting in the formation of a two-phase flow. This can distort flowmeter readings and lead to significant measurement errors and increased technical losses.

Thus, a comprehensive approach to the design of LNG dispensers includes selecting materials with high thermal resistance, optimizing insulation, and implementing advanced measurement technologies. These measures allow for minimizing errors and enhancing the accuracy of fuel accounting.

Main Refueling Schemes and the Typical Technological Scheme of a Fuel Dispenser:

When refueling the cryogenic tank of a vehicle (CVT), the primary objective is to achieve maximum filling, as this determines the distance the vehicle can travel on a single fill. However, LNG storage is accompanied by a boiling phenomenon, during which boil-off gas (BOG) is generated. To regulate pressure, excess BOG is either vented into the atmosphere or returned to the refueling station, depending on the BOG management system.

Unlike traditional gas station dispensers, cryogenic LNG refueling stations must account for both the dispensed and received gas. Different vehicle fuel systems have specific requirements for LNG temperature (e.g., “warm” or “cold” LNG) and possess various design differences in the technological scheme, which directly affect the selected refueling scheme and method. Figure 1 shows the appearance of an LNG dispenser.

Figure 1. Appearance of an LNG dispenser

The following types of refueling operations can be distinguished:

1. connecting the liquid-phase nozzle without BOG reception;
2. connecting both liquid-phase and vapor-phase nozzles with simultaneous BOG reception;
3. connecting the liquid-phase nozzle, where BOG is received through the same hose.

When only the liquid-phase nozzle is connected, excluding BOG reception, measurement accuracy is at its highest. In this case, it is determined solely by the accuracy of the liquid-phase Coriolis flowmeter. However, the refueling time increases due to pressure buildup in the system. Nevertheless, when BOG accounting is required, or when it is received through the liquid-phase nozzle, the task becomes significantly more complex.

In such cases, additional flowmeters are required, making it necessary to control the absence of liquid or two-phase flow through the BOG flowmeter. The presence of a two-phase flow can significantly distort readings and lead to a cumulative error no less than the error of the two flowmeters used.

This task becomes particularly challenging in fuel systems such as those in Volvo vehicles, where design features include BOG reception through the same hose as the liquid-phase supply. In such cases, it is critically important to ensure single-phase flow through the flowmeter, as the presence of a two-phase flow will result in inaccurate measurements, and waiting for LNG evaporation will increase refueling time. For such complex configurations, it is advisable to use two flowmeters and conduct BOG reception through a separate flow, allowing for improved accuracy and efficiency in the refueling process.

The typical technological scheme of an LNG dispenser is shown in Figure 2.

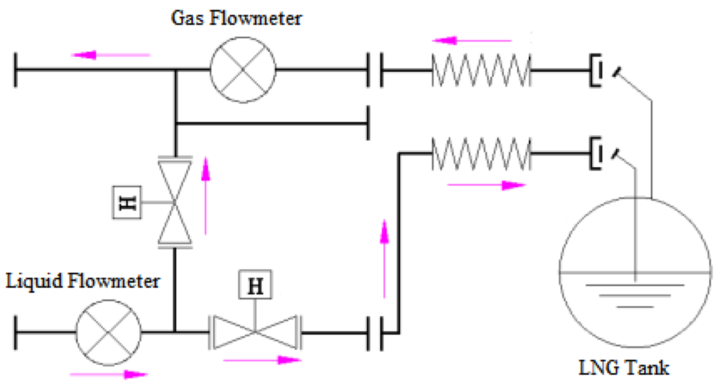

Figure 2. Technological scheme of an LNG dispenser

2. Typical Technological Scheme of LNG Dispensers

An LNG dispenser generally consists of two flowmeters, pressure sensors, and shut-off control valves (SCVs). Coriolis flowmeters are the most commonly used due to their versatility and ability to operate across a wide range of flow rates while providing high measurement accuracy comparable to that of the best volumetric flowmeters. The advantages of Coriolis flowmeters include:

The ability to function across a wide range of flow rates, making them adaptable to various operational modes.

High measurement accuracy, ensuring minimal error comparable to the best volumetric flowmeters.

Compact design, reducing installation space and simplifying assembly. The ability to measure flow in both directions, offering additional flexibility in system design.

Lower maintenance costs due to durability and resistance to wear. To achieve the required measurement accuracy, which may vary from 1 to 1.5% depending on legislative requirements, it is critical to eliminate the possibility of two-phase flow through the flowmeter. This is achieved by selecting valves with a high class of tightness and strictly following the manufacturer's recommendations when installing equipment on technological pipelines.

Key Technical Challenges in Designing LNG Dispensers. When designing and operating LNG dispensers, the cryogenic properties of LNG must be considered, as LNG storage temperatures reach as low as -162 °C. Even minor temperature increases can cause the liquid to boil and form BOG, leading to the creation of a two-phase flow. The presence of such a flow can result in undesirable effects, such as bubble effects, resonator effects, and uneven bubble distribution, which significantly reduce measurement accuracy.

According to research, additional errors due to bubble effects can reach 2%, while resonator effects contribute up to 0.04%. Such deviations make it impossible to meet legislative requirements for the commercial accuracy of fuel dispensing measurements. Depending on the thermal conductivity of the insulation, the rate of temperature increase and two-phase flow formation will vary, playing a crucial role during system transitions between different states.

To prevent heat losses and stabilize the refueling process, it is recommended to use high-performance insulation materials such as:

1. Aerogel: Distinguished by low thermal conductivity and non-flammability, making it suitable for cryogenic applications.
2. Polyisocyanurate (PIR) insulation: Can be used under less stringent fire safety requirements but requires a thicker insulation layer.
3. Vacuum-jacketed pipelines: Effectively minimize heat transfer and maintain the conditions necessary for single-phase flow.

The use of such materials not only improves measurement accuracy but also reduces operating costs by ensuring system durability and process stability.

In the Russian Federation, aerogel is considered the most suitable insulation material due to its low thermal conductivity compared to PIR and its non-flammability, which makes it a safe and reliable option for meeting strict fire safety requirements. Where non-flammable materials are not mandatory, PIR insulation can be used, but its higher thermal conductivity necessitates increased insulation thickness to achieve the same performance as aerogel.

Significance of Shut-Off Control Valves (SCVs): The choice of SCVs significantly affects measurement accuracy. Improperly selected valves, whether due to insufficient tightness or slow actuation, can result in leaks around the measurement instruments or directly into the environment. Even minimal leaks can lead to substantial measurement errors, economic losses, and increased environmental risks, particularly when LNG is used as an environmentally friendly fuel.

The reliability of SCVs and their ease of maintenance are also critical, as frequent switching during regular operation causes natural wear of components. Therefore, it is essential to select valves capable of maintaining tightness under conditions of repeated switching.

Accurate summation of received and dispensed LNG volumes, as well as the protection of control systems and software from external interference that could distort accounting results, play a crucial role in ensuring measurement accuracy. Reliable integration of such systems minimizes errors and improves data reliability at all stages of the process.

3. Algorithms and Automation in LNG Refueling

The accuracy of measurements during LNG refueling heavily depends on the algorithms embedded in the dispenser systems. Key factors, such as the initial condition of the hose (empty or full), directly impact the need for pre-cooling or the time required for boil-off gas to escape the hose. For example, when refueling from an empty hose, LNG boiling occurs, resulting in increased pressure and disruption of measurement accuracy.

Effective refueling algorithms should include the following functionalities:

1. Automatic Shutdown: Control of flow and pressure parameters allows for stopping the refueling process when predefined values are reached. For instance, a decrease in flow rate and an increase in vehicle tank pressure indicate that the tank is full or that boil-off gas management is required.

2. Medium Density Control: During refueling with a vapor-phase nozzle, increasing density at the boil-off gas flowmeter may indicate LNG overflow, requiring process adjustment.

3. Closed Loop Pressure Monitoring: Monitoring prevents excessive activation of safety valves and ensures process stability, minimizing the risk of leaks and damage to the pipeline system.

4. Grounding, Flow, Pressure, and Temperature Monitoring: Continuous monitoring of these parameters enables timely detection of potential malfunctions, such as hose rupture, and the implementation of measures to minimize risks.

4. Conclusion

Measurement accuracy during LNG refueling requires a comprehensive approach that considers LNG's properties, pipeline design, insulation quality, and system operation algorithms. This research highlights the critical measures needed to enhance accuracy and efficiency, including:

1. Insulation: The use of high-performance insulation materials reduces heat transfer, preventing the transition of LNG to a two-phase state and improving measurement accuracy.

2. Control Valves: High-sealing, quick-acting shut-off control valves minimize leaks and ensure flow stability.

3. Refueling Algorithms: Algorithms that account for equipment conditions and flow parameters provide a more precise and reliable refueling process.

4. Monitoring Systems: Systems that continuously monitor pressure, temperature, and flow ensure rapid detection and prevention of potential disruptions, maintaining stable operation.

The implementation of these measures improves measurement accuracy, reduces operational costs, and promotes the environmentally friendly use of LNG as an alternative fuel.

REFERENCES

[1] *Xu, Jingjing, David Testa, and Proshanto K. Mukherjee*. 2015. "The Use of LNG as a Marine Fuel: The International Regulatory Framework." Ocean Development & International Law 46 (3): 225–40. doi:10.1080/00908320.2015.1054744.

[2] *Smajla, I., Karasalihović Sedlar, D., Drljača, B., & Jukić, L.* (2019). Fuel Switch to LNG in Heavy Truck Traffic. Energies, 12(515). doi: 10.3390/en12030515.

[3] *Rodkin, Y.E., Zaitsev, A.V., & Sulin, A.B.* "Ways to Reduce LNG Losses during Transportation and Storage." Bulletin of the International Academy of Refrigeration, 2023, No. 4, pp. 44–50. doi:10.17586/160643132023224-44-50.

[4] *Kim H-S, Cho C-H.* "An Economical Boil-Off Gas Management System for LNG Refueling Stations: Evaluation Using Scenario Analysis." Energies, 2022, 15(22):8526. https://doi.org/10.3390/en15228526.

[5] *Gorbachyov, S.P., and Popov, V.P.* "Modern Cryogenic Onboard Fuel Systems for LNG-Powered Vehicles." Transport on Alternative Fuels, 2008, no. 6(6), pp. 66–69.

[6] *Gorbachyov, Stanislav Prokofievich, and Kirienko, Kristina Igorevna.* "The Influence of Real Factors on Refueling Cryogenic Onboard Fuel Systems of LNG Vehicles." Transport on Alternative Fuels, 2015, no. 2(44), pp. 12–17.

[7] *Xiong, M., Yang, J., Zhao, P., Yu, B., Deng, W., & Lin, J.* "Liquefied Natural Gas (LNG) Dispenser Verification Device." In SPIE Proceedings: Eighth International Symposium on Precision Engineering Measurement and Instrumentation, vol. 8759, 87594F. doi: 10.1117/12.2014911.

[8] *Wu, T., Kenbar, A., & Pruysen, A.* "LNG Mass Flowrate Measurement Using Coriolis Flowmeters: Analysis of Measurement Uncertainties." Measurement, 2021, vol. 177, 109258. doi: 10.1016/j.measurement.2021.109258.

[9] *Pushnov, A.V.* "Measuring Two-Phase Flow Rates Using Coriolis Flowmeters." Measurement Techniques, 2013, no. 4, pp. 45–48.

[10] *Kravchenko, M., Ricken.* "Flow Rate Measurements Using Coriolis Flowmeters in Two-Phase Flow." In Application of Coriolis Flowmeters in Light of GOST R 8.615-2005. Legislative and Applied Metrology, 2006, no. 4, pp. 37–44.

[11] *Bezdenezhnykh, I., & Beznosov, A.* "Peculiarities of Cryogenic Pipelines Insulation Selection at Small-Scale Liquefied Natural Gas Production and Consumption Facilities." E3S Web of Conferences, 2024, vol. 498, 01006. doi: 10.1051/e3sconf/202449801006.

[12] *Shammazov, I., and Karyakina, E.* "The LNG Flow Simulation in Stationary Conditions through a Pipeline with Various Types of Insulating Coating." Fluids, 2023, vol. 8(2), 68. https://doi.org/10.3390/fluids8020068.

Acknowledgements

I would like to express my gratitude to Alexander Parfenov for his valuable ideas and technical expertise, which I frequently sought during the preparation of this article.

Authors' biographies

Ilya Bezdenezhnykh is a PhD student at Ural Federal University (UrFU) and a project engineer specializing in small-scale LNG technologies. He also works as a process engineer, focusing on the development and optimization of LNG production and refueling station designs. His primary research interests include electromechanics and electromechanical systems, LNG production technologies, and the reduction of technological losses in LNG operations. Ilya's work aims to enhance the efficiency and sustainability of LNG refueling infrastructure while addressing critical challenges in cryogenic systems. His expertise contributes to advancing innovative solutions in the field of small-scale LNG applications.

Email: bezdenezhnykhin@gmail.com