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Simulation Study for Flow Assurance of Thai Binh Liquefied Natural Gas Supply Pipeline by Using OLGA Software

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Abstract

The natural gas supply in Vietnam is progressively declining; therefore, the strategy of importing LNG (Liquefied Natural Gas) is currently an urgent solution to ensure national energy security. The main component of LNG is methane, which is liquefied through deep refrigeration for storage and transportation. According to Power Development Plan VIII, by 2030, the country is expected to have about 24 GW of power generated from LNG. Ensuring stable flow (flow assurance) is a key factor in the LNG transportation system. This study focuses on calculating the operating conditions in the LNG supply pipeline using OLGA software. Based on the transported gas flow rate, the study conducts steady-state simulations as the basis for calculating the transient state of the pipeline. The transient results indicate the need to reinforce the initial segment of the pipeline with thermally insulated alloy steel, control hydrate formation using hydrate inhibitors, conduct regular pigging, assess the risk of system shutdown, and manage depressurization operations. These results serve as a foundation for the effective and safe design and operation of the LNG supply system.

Keywords: Flow assurance, liquefied natural gas, modeling, pipeline.

1. Introduction

Amid the continuous growth of the global population and accelerating industrialization, global energy demand has risen significantly, with oil and natural gas accounting for more than 65% of total primary energy sources [1]. In recent years, liquefied natural gas (LNG) has been increasingly regarded as a "bridge fuel" toward a sustainable energy system, particularly in the period after 2050 [2, 3]. This perception has driven the rapid development of large-scale LNG processing, storage, and transportation activities worldwide [4]. In parallel with this trend, many countries are shifting their focus toward the exploitation and utilization of natural gas due to its advantages such as abundant supply, economic efficiency, and lower environmental impact.

Vietnam has been experiencing rapid economic development driven by industrialization and modernization, leading to a sharp increase in electricity production and consumption. Electricity output rose from 26.7 million kWh to 208 million kWh between 2001 and 2010, while per capita electricity consumption increased sixfold. According to the National Power Development Plan VIII, electricity demand in Vietnam is expected to grow at a rate of 7% per year over the next decade-higher than many other Asian countries [5].

In the context of electricity shortages, declining traditional fuel sources, and the urgent need for carbon emission reductions, imported LNG and gas-fired power plants have emerged as viable solutions to ensure energy security for Vietnam [6]. Vietnam's commitment to LNG came at a critical moment for the global gas market, which was facing a supply glut due to expanded U.S. production and reduced demand caused by COVID-19. This led suppliers to aggressively promote large-scale LNG projects, with the United States playing a prominent role, often supported by the outgoing Trump administration [7].

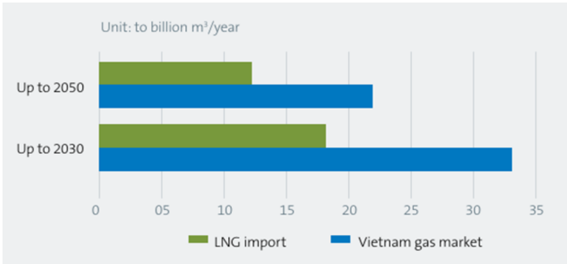

Fig. 1. Gas market and LNG import forecast for Vietnam

In addition, the challenges related to ensuring flow in the natural gas pipeline system are also pressing issues for many countries, including Vietnam. In the offshore oil and gas exploration and production industry, ensuring stable flow for gathering and transportation systems becomes a critical factor for operational safety. This is due to the complexity of the components in the pipeline, the rugged seabed terrain, the low temperatures at the seabed, along with the multiphase flow patterns that change due to the shape of the pipe and operational changes. Ensuring flow must address issues such as deposition of solids, erosion and corrosion, hydrate formation, as well as pipeline vibration due to flow, to prevent the economic losses caused by unexpected shutdowns [8]. In Vietnam, these challenges are even

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more severe due to the lack of infrastructure coordination, favorable deep-sea environmental conditions for hydrate formation, and the limited application of advanced simulation technologies. Based on this, the research focuses on analyzing typical risks affecting the natural gas transportation process, while proposing appropriate design and operation solutions to ensure safety, continuity, and economic efficiency for the gas pipeline system in Vietnam.

The objective of this study is to evaluate the pressure changes, temperature distribution, and flow rates based on actual operating conditions, to identify pipeline sections with low temperatures during LNG transportation to select suitable materials. In addition, the study also simulates the operational state of offshore and onshore pipelines to assess processes such as pump-off and lift-off, shutdown systems, and pressure reduction scenarios, thereby ensuring the integrity and safety of the operating system.

2. A Brief Overview of Flow Assurance

Flow assurance is an important field in the oil and gas industry, particularly related to the transportation of natural gas and other fluids through pipelines [9]. A key safety issue in this field is the formation of hydrates in gas pipelines in deepwater regions [10]. Factors such as inlet and outlet pressure, pipeline slope, and chemical treatment also affect the flow. Additionally, it is necessary to assess the depressurization venting process to select suitable materials for the vent pipeline, ensuring that the depressurization process is operated safely [11]. In summary, flow assurance focuses on maintaining stable, safe, and efficient flow by preventing and mitigating potential issues such as hydrates, corrosion, and undesirable flow patterns. The use of simulation tools and risk analysis plays an important role in achieving this goal.

The process of receiving and distributing LNG from the Floating Storage Regasification Unit (FSRU) is carried out through a series of specialized pipeline systems. LNG is pumped out of the FSRU through a flexible hose system combined with a suspended rigid pipeline, ensuring flexibility and safety in the connection. The LNG flow is then routed through a low-temperature pipeline system. From here, LNG continues to be transported via an offshore subsea pipeline to the Landfall Station (LFS), where the system is equipped with safety devices including Shutdown Valves (SDV), a Flare System, along with pressure and temperature measurement devices to control and monitor operational conditions. After passing through the LFS, LNG continues through the onshore pipeline. Finally, after undergoing necessary checks and ensuring safety parameters, the gas flow can be vented to a safe area if required before being transferred to the Gas Distribution Station (GDS) for introduction into the domestic consumption system.

3. Methodology

The system consists of a network of interconnected pipeline segments. The starting point is from the FSRU located about 24 km from the mouth of the Tra Ly River, Thai Binh, and the final receiving point is the GDS at the Thai Binh Power Plant. The transported fluid is natural gas from sources of Tokyo Gas, aiming to supply gas to the Thai Binh LNG Power Plant.

To study the flow assurance challenges related to the operation of the gas pipeline system from the FSRU to the GDS at the Thai Binh Power Plant, hydraulic data were collected from Kyuden International Corporation (KIC) and Truong Thanh Vietnam Group (TTVN Group). The pipeline network has a total length of approximately 27 km, including two main segments divided by the landfall point (LFP):

- Segment 1: offshore, DN500 pipeline, DNV-ST-F101 standard, transporting LNG from the FSRU to the LFS;

- Segment 2: onshore, DN500 pipeline, ASME B31.8 standard, connecting the LFS to the GDS at the Thai Binh Power Plant.

This study uses simulation to assess flow assurance, with analyses of steady-state and transient (unsteady-state) conditions to propose safe operational principles. The hydraulic study was performed using OLGA software version 2022.1.0, and the gas composition was simulated using Multiflash software.

For the steady-state simulation, scenarios were built based on steady flow rates, including the normal flow case, the minimum flow case, and the maximum flow case. The purpose of these simulations is to evaluate the hydraulic characteristics under steady-state conditions of the system, including assessment of the maximum gas velocity, pressure drop along the pipeline, pressure at the FSRU, pressure at the GDS, pipeline temperature, hydrate formation potential, and determination of the length of the low-temperature pipe segment. The steady-state simulations were performed with various input parameters such as fluid composition, gas flow rate, ambient temperature, and operating pressure fixed at the FSRU or GDS.

In addition, the report conducts transient (unsteady-state) simulations to evaluate dynamic phenomena within the pipeline. The studies in the transient simulations include pigging operations from the Pig Launcher (PL) station located near the FSRU at the starting point of the offshore pipeline to the Pig Receiver (PR) station located at the GDS, pipeline shutdown, and pipeline depressurization (De-pressurization - DP). The pipeline simulation models were built based on the pipeline system diagram.

Input data for the simulations included process parameters such as fluid composition, gas flow rate, pipeline pressure and temperature, pipeline physical data (dimensions, roughness, depth, material, and coating), and environmental data (seawater and air temperature).

The simulation results for each scenario are presented in detail, accompanied by charts and data tables, providing the basis for recommendations to ensure safe and efficient flow assurance for the system.

4. Simulation Model Setup Utilizing Existing Data

The pipeline system diagram for steady-state and transient simulations was developed using OLGA software. Fig. 2 illustrates the LNG supply from the FSRU, the key nodes in the pipeline model (FSRU, LFP, LFS, GDS), the main pipeline sections (FSRU-LFP, LFP-LFS, LFS-GDS), the depressurization point (DP Point), and the vent valve control system for depressurization operations (DP Controller).

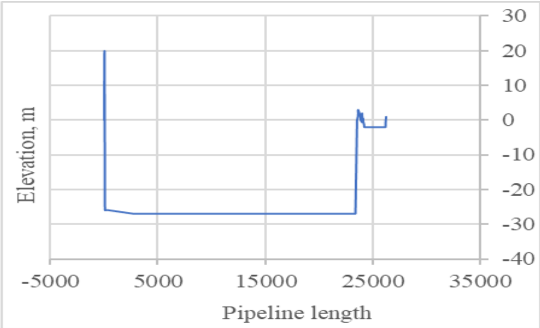


Fig. 3. Overall Pipeline Profile from FSRU to GDS

The operating pressure at the GDS is fixed, while the temperature of the LNG flow inside the pipeline follows ambient conditions. The mass flow rate of LNG feed stream is fixed at FSRU.

The length and height of the pipe are simulated according to the data in Fig. 3.

Table 1. Process data input for simulations

	Condition	*Parameter*
Pressure	Operating, min/max, barG	40/60
	Design, barG	98
Temp	Operating, min/max, °C	4.1/39.2
	Design, min/max, °C	-10/65

The LNG consumption flow rate expected is shown in the Table 2.

Table 2. LNG Flow rate

Simulation Case	*Flow rate (MTPA)*
Min Case	0.51
Normal Case	1.03
Max Case	1.50

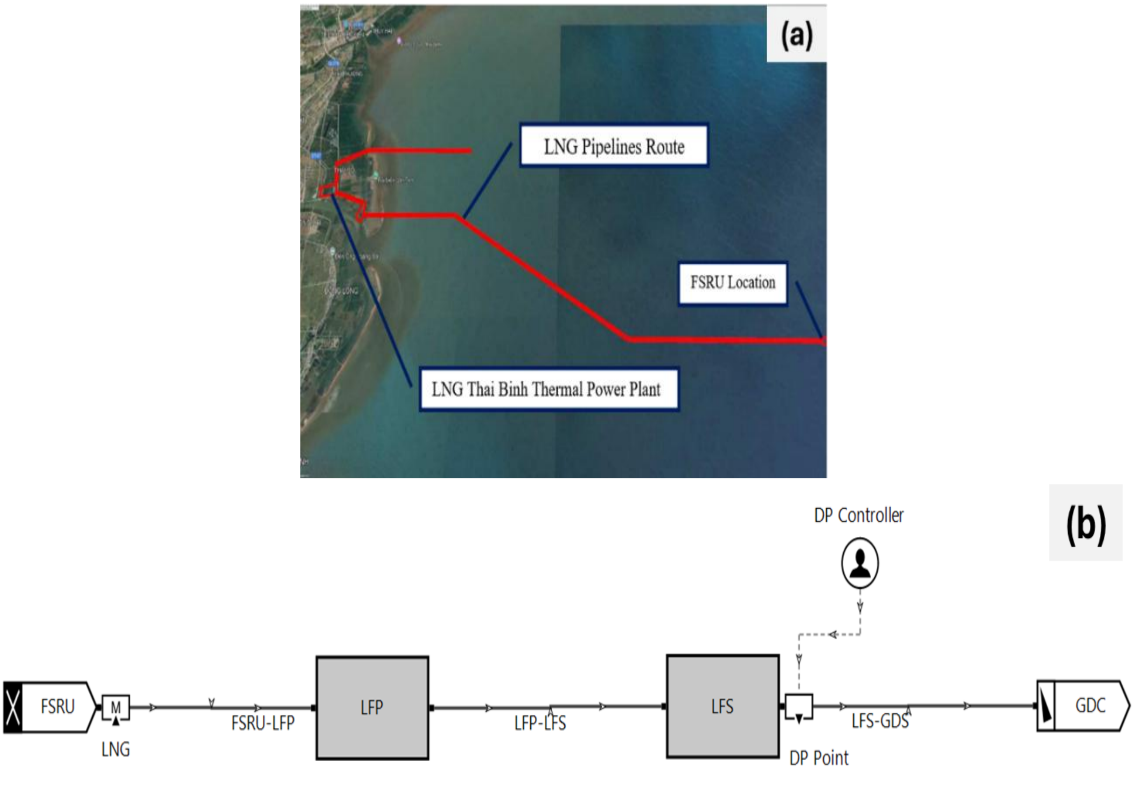


Fig. 2. Pipeline route layout on Google Maps from FSRU to GDS (a) and system simulation diagram (b)

The design parameters for the pipeline are shown in the Table 3:

Table 3. Pipeline and coating data

Route	Length (*km*)	Diameter		Wall thickness (mm)	3LPE (*mm*)	Concrete (*mm*)	Roughness (*mm*)
		ID	OD				
FSRU - LFP	23.80	484	508	12	3.5	40	0.0015
LFP - LFS	0.17	484	508	12	3.5	40	0.0475
LFS - GDS	2.22	484	508	12	3.5	40	0.0475

The environment temperature data used in the simulation are shown in the Table 4, [12]:

Table 4. Environmental data [12]

Parameter	Min	Max	Average
Surface Sea Water Temp, °C	24.2	30.5	-
Seabed Water Temperature, °C	15	28.9	-
Air Temperature, °C	4.1	39.2	23.4

5. Results

5.1. Steady State Analysis

5.1.1. Gas velocity and pressure drop

The pipeline system was designed to transport LNG with a maximum flow rate of up to 9.1 MMSCF (equivalent to 100% design capacity). In the maximum flow rate case, gas velocity and pressure drop were analyzed to assess compliance with API 14E and NORSOK, which are gas pipeline standards that consider factors such as gas velocity, pressure drop, pipe material, and erosion rate to ensure safe pipeline operation. The results are presented in the Table 5, serving as a basis for comparison and evaluation against the relevant standards.

Table 5. Velocity and pressure drop along pipelines

	FSRU-LFS	LFS-PV	PV-GDS
Max velocity (m/s)	9.81	12.05	12.36
Pressure drop (kPa/100m)	5.00	5.14	5.38

5.1.2. Hydrate formation potential

To evaluate the hydrate formation potential along the pipeline, simulations were conducted under extreme conditions, defined by low ambient temperatures and maximum inlet pressure. These scenarios aim to assess the risks of hydrate formation under severe operating envelopes, which may occur during cold weather or transient conditions.

Using OLGA, the difference between hydrate and fluid temperature (DTHYD) was analyzed across operational flowrates (Table 2). The results indicate that hydrate formation is most likely to occur at the FSRU inlet and the LFS – GDS segment, where the fluid temperature falls below the hydrate formation temperature.

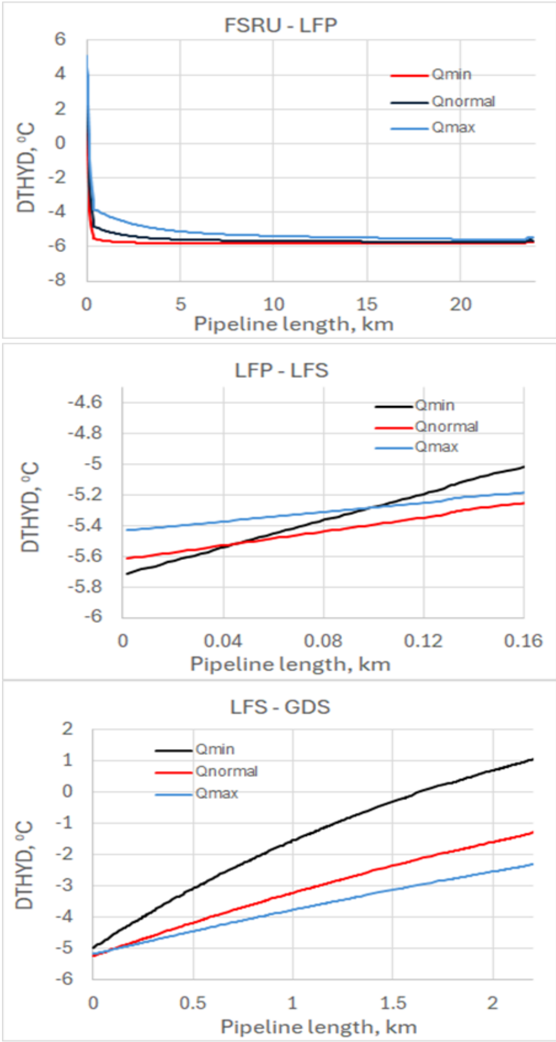


Fig. 4. Different between hydrate and fluid temperature

5.1.3. Low-temperature pipeline

During the operation of the FSRU, the worst-case scenario involves the ingress of LNG (liquid at approximately –162 °C) into the pipeline system due to an incident at the FSRU. In such cases, the LNG temperature entering the pipeline can reach as low as –120 °C, imposing a sudden thermal shock on carbon steel lines and potentially causing brittle fracture. Therefore, it is essential to determine the required length of low-temperature-resistant pipeline to protect the system. The results of this analysis provide a basis for selecting appropriate pipeline materials for this extreme condition.

5.2. Transient Analysis

5.2.1. Pipeline pigging analysis

Pigging is recommended during pre-commissioning, emergency, or scheduled maintenance activities to remove construction debris, accumulated liquids, or to verify pipeline cleanliness and mechanical integrity. In this study, a pigging operation is simulated under maximum flow conditions (1.5 MTPA), maximum ambient temperature, and a steady outlet pressure of 60 barg at the GDS. The pig is launched from the pig launcher near the FSRU and received at the GDS.

The simulation results are used to evaluate the pig's velocity, ensure it remains within an acceptable operational range, and confirm that the pig is able to traverse the entire pipeline. Determining the total pigging time is essential for planning isolation durations, coordinating field operations, and ensuring safe pressure control at both ends during the run.

The main plot and trend profiles are shown in Fig. 6.

5.2.2. Transient shutdown scenario analysis

Shutdown simulations were performed to evaluate system pressure behavior during emergency events. When shutdown occurs at the GDS while the FSRU remains operating, the pipeline pressure increases and may exceed the design limit of 98 barg. In contrast, shutdown at the FSRU results in a gradual pressure drop along the pipeline.

The simulations aim to assess pressure evolution and provide operators with estimated response times to take action before overpressure occurs.

Results of the simulations are tabulated in the Table 6.

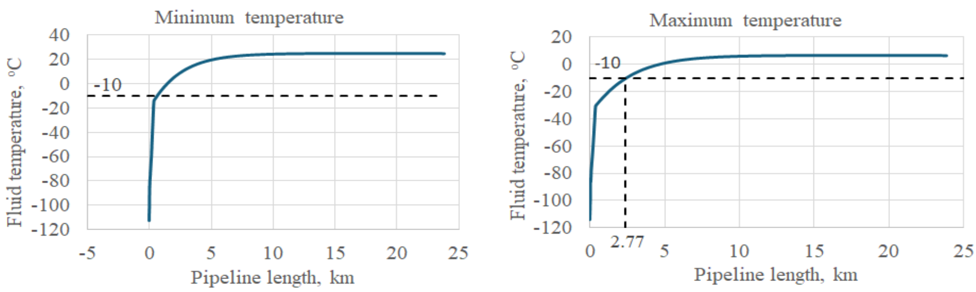


Fig. 5. The length of the low-temperature pipeline at different temperature conditions

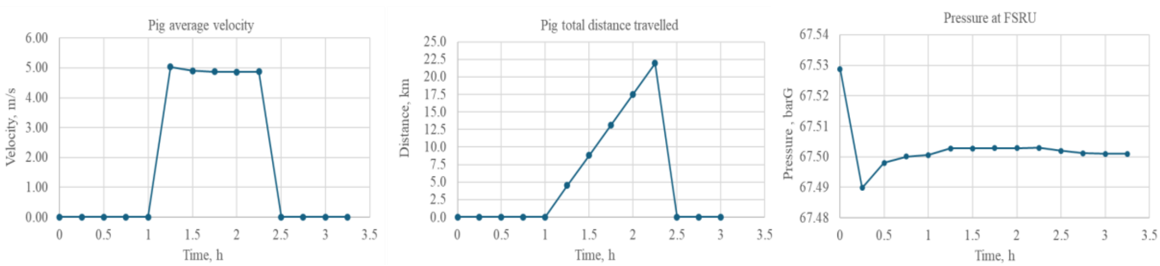


Fig. 6. Pipeline pigging results

Table 6. Operating conditions prior to system shutdown for each case

Cases	Flow rate before shutdown *(MTPA)*	Pressure at location shutdown *(barG)*	Location Shutdown	Temperature *(°C)*
SD1	1.50	60.00	At GDS	39.20
SD2	1.50	40.00	At GDS	39.20
SD3	1.80	60.00	At GDS	39.20
SD4	1.80	40.00	At GDS	39.20
SD5	1.50	60.00	At FSRU	39.20
SD6	1.50	40.00	At FSRU	39.20
SD7	1.80	60.00	At FSRU	39.20
SD8	1.80	40.00	At FSRU	39.20

The main trends and profiles are shown in Fig. 7:

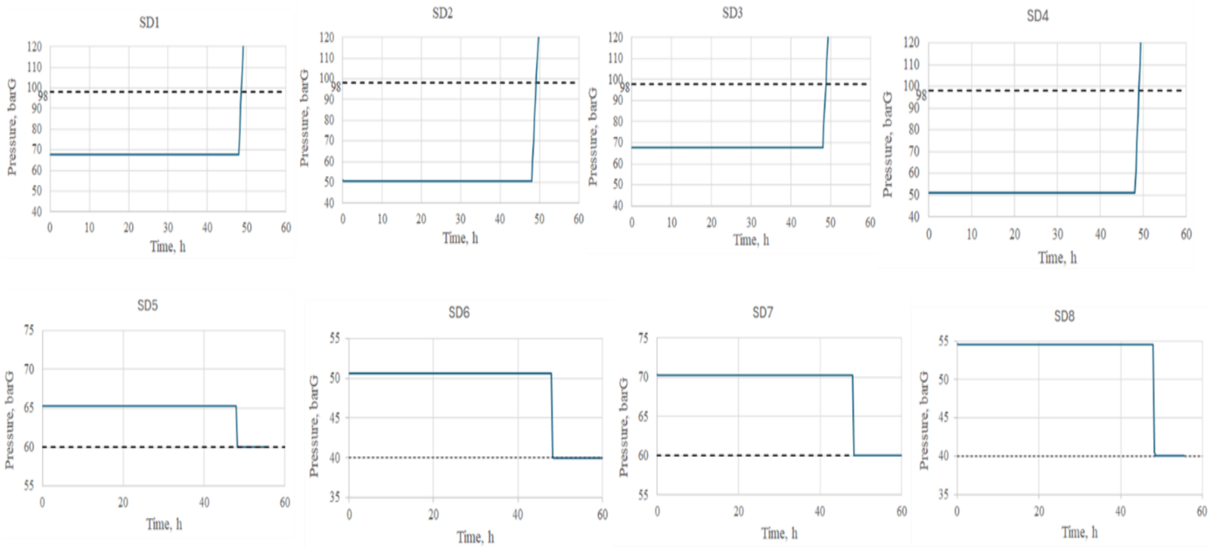


Fig. 7. Pressure at FSRU under shutdown scenarios

5.2.3. De-pressurization study

Pipeline de-pressurization is assumed to begin after 2 days of steady state operation to get stability flow. The pipeline will be depressurized in scenario maximum flow rate 1.50 MTPA, maximum ambient temperature and 60 barg – the maximum pressure at GDS, then through the flare system at LFS, with back pressure from the flare system estimated at 1.5 barg.

The main trends and plots are shown below:

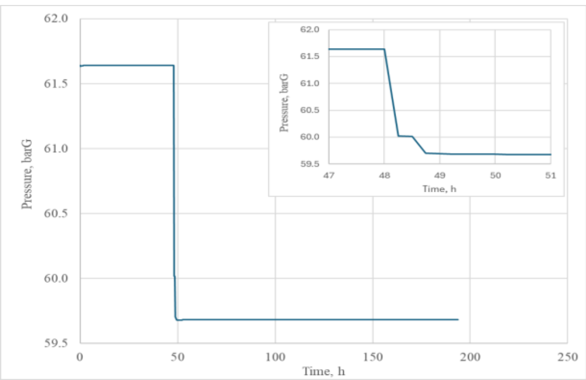
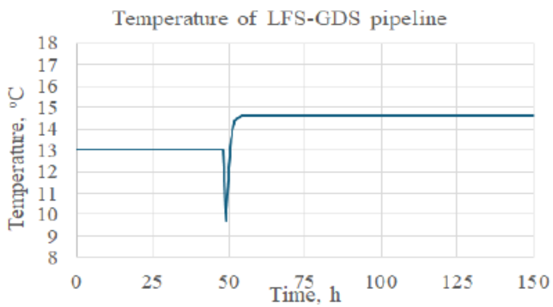


Fig. 8. Time for de-pressurization process



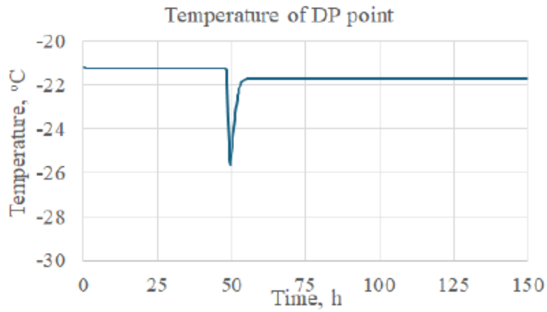


Fig. 9. Temperature at the de-pressurization point and temperature in the pipeline

6. Discussion

This study employed the dynamic simulation software OLGA to evaluate the operational performance of the LNG supply pipeline originating from the FSRU. Simulation results indicate a risk of hydrate formation in the LFS–GDS section under cold ambient conditions, highlighting the necessity for thermal insulation or the injection of appropriate inhibitors. In the worst-case scenario, where liquid-phase LNG infiltrates the system, the model was able to identify the pipeline segment exposed to cryogenic temperatures, thereby providing a technical basis for selecting suitable pipe materials.

Beyond the specific technical findings, the study contributes to the scientific database for the design of LNG supply systems in tropical offshore environments, which pose unique challenges such as deep-water conditions, seabed geometry variations, and significant ambient temperature differentials. Simulations of shutdown and depressurization events offer critical insights for the development of emergency response protocols, the integration of additional safety mechanisms, and the optimization of control systems.

The proposed methodology can be applied to other LNG transmission pipelines in Vietnam and the broader region, particularly in the context of increasing reliance on imported LNG.

Based on the results of the steady-state and operational analyses conducted in this study, the following recommendations are proposed to ensure the safe and efficient operation of the Thai Binh LNG pipeline system.

6.1. Gas Velocity and Pressure Drop

The gas flow velocity within the pipeline reaches a maximum of 12.36 m/s, complying with API 14E standards, which require gas velocity not to exceed 60 ft/s (approximately 18.29 m/s).

The pressure drop along the pipeline sections meets the recommended range of 11–27 kPa/100 m for gas pipelines operating at pressures of 35–138 barg.

6.2. Low-Temperature Pipeline

When cryogenic LNG enters the pipeline due to an incident, it rapidly absorbs heat and increases in temperature along the pipeline. The distance over which the fluid remains below –10 °C, varies with ambient conditions, extending up to 2.77 km in cold environments. This zone presents a risk of brittle fracture if conventional carbon steel is used. Therefore, it is recommended to designate this segment as cold-resistant, using materials such as ASTM A333 low-temperature carbon steel, combined with thick insulation, thermal expansion provisions, and continuous temperature monitoring [13].

6.3. Hydrate Formation Prevention

The analysis indicates a potential risk of hydrate formation in the LFS to GDS section and around the FSRU area under extreme operational conditions, specifically at low ambient temperatures and maximum inlet pressure. This potential risk was observed across all flowrate scenarios, including minimum, normal, and maximum LNG flowrate cases. Hydrate can cause flow blockage, pressure accumulation, and threaten pipeline integrity, resulting in safety and operational concerns.

To mitigate these risks, a hydrate inhibitor injection system is recommended at the LFS. In addition, insulation or active heating should be considered for pipeline segments exposed to low temperatures, particularly during winter operation or conditions leading to an increase in system pressure, both of which can enhance the probability of hydrate formation.

6.4. Pigging Operations

Pipeline pigging is typically carried out during maintenance or emergency scenarios to clean the line and ensure its operability. In the simulated case, the pig successfully traveled the entire pipeline length without signs of stalling or obstruction, indicating smooth and uninterrupted movement throughout the operation.

The maximum pig travel time is approximately 1.5 hours. An average pig velocity of 5.03 m/s falls within the recommended range for gas pipeline pigging operations, typically between 2 and 7 m/s [14], ensuring effective cleaning and safe operation.

Pigging operations should be carefully scheduled to minimize operational disruptions and ensure proper monitoring of pig movement [15].

6.5. Shutdown Considerations

In GDS shutdown events, if the FSRU continues operation, the pipeline pressure will reach the maximum pressure (98 barg) within 0.74–1.17 hours (40-60 barg). At 120% flowrate, the pressure rises more rapidly, and the response time shortens to approximately 0.62–0.99 hours. This accelerated pressure buildup highlights the need for appropriate overpressure protection systems, such as pressure reducing valves at critical points, to prevent equipment damage and maintain system safety. After this period, the GDS system has not yet recovered, requiring both the onshore processing system and offshore equipment to shut down; otherwise, pressure may exceed the allowable limit, leading to pipeline overstress or mechanical failure.

In shutdown FSRU events, GDS continues to receive LNG, the pressure in the pipeline decreases to the GDS operating pressure within 0.25–0.51 hours. At 120% flowrate, the depressurization period is slightly longer, from 0.33 to 0.52 hours. Once the pipeline pressure equalizes with the pressure at the GDS, gas can no longer be transported. At this point, the pipeline should be isolated to retain the remaining gas and prevent unnecessary losses and environmental pollution, until the FSRU system is able to resume operation.

In addition, automated shutdown control systems should be implemented to ensure timely intervention under both emergency and non-emergency abnormal conditions.

6.6. Depressurization

Depressurization of the pipeline should be carried out via the flare system at the LFS. The released gas is safely combusted to prevent direct hydrocarbon emissions into the atmosphere, minimizing environmental impact and eliminating explosion risks during emergency or maintenance operations.

The estimated time from the start of depressurization to reaching the target pressure is approximately 48.56 hours; however, it is recommended to maintain the depressurization process for at least 49.49 hours to ensure complete pressure stabilization across the system before any further operations are resumed.

The pipeline temperature is 9.67 °C, which is within the safe operating range; however, the pressure at depressure point drops to -25.66 °C, which may pose a risk to material integrity. It is recommended to verify pipeline material selection to withstand low temperatures during depressurization even

7. Conclusion

This study utilized the OLGA dynamic simulation software to analyze the operational behavior of the LNG pipeline supplying gas from the FSRU to the ThaiBinh onshore facilities. The results indicate a risk of hydrate formation in the LFS–GDS section under low ambient temperatures, requiring the application of thermal insulation or an appropriate hydrate inhibitor system. Under worst-case scenarios involving LNG ingress, the model identifies the pipeline segments exposed to cryogenic temperatures, serving as a basis for selecting suitable pipe materials. In addition to specific technical findings such as flow velocity, pressure drop, pigging duration, and depressurization time via flare, the study contributes to the design database for LNG pipeline systems in tropical marine environments. These regions present unique challenges in seabed slope, water depth, and temperature variation. The proposed methodology, including shutdown and emergency simulations, supports the development of control systems and safety responses. It can be extended to other LNG transmission projects in Vietnam and neighboring countries, especially in the context of increasing reliance on imported LNG.

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