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DEVELOPING METHODS TO IDENTIFY AND REDUCE LOSSES DUE TO EVAPORATION DURING THE TRANSPORTATION AND STORAGE OF GTL SYNTHETIC LIQUID FUELS

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Muradova Firuza Rashidovna
Professor, Bukhara State Technical University
Qobilov Azamat Beshim o'g'li
Master's Student, Bukhara State Technical University

Abstract

This study analyzes the losses of GTL (Gas-to-Liquid) synthetic liquid fuels during transportation and storage caused by evaporation. The research identifies the main causes of losses, methods for their measurement, and strategies to minimize them. Technical and organizational measures to reduce evaporation, including pressurized storage, closed systems, and monitoring implementation, are discussed. The findings contribute to improving the economic and environmental efficiency of GTL fuel storage and transportation processes.

Keywords

GTL fuel, evaporation, losses, transportation, storage, monitoring system, economic efficiency

Introduction

GTL (Gas-to-Liquid) synthetic liquid fuels produced using GTL technology are currently considered one of the strategically important types of fuels in the energy sector. These fuels are obtained through the deep processing of natural gas and are distinguished by their low sulfur content, minimal aromatic compounds, and high combustion efficiency. As a result, GTL fuels are environmentally cleaner compared to conventional petroleum products and can be widely used in internal combustion engines, aviation and railway transport, as well as in energy generation equipment.

At the same time, certain physicochemical properties of GTL fuels, such as fractional composition, saturated vapor pressure, and temperature sensitivity, make them prone to evaporative losses during storage and transportation. Losses due to evaporation lead to a reduction in the actual volume and mass of the fuel, directly causing economic damage. In addition, the release of evaporated fuel into the atmosphere increases emissions of volatile organic compounds (VOCs), which negatively affects the environment and creates situations that violate ecological safety requirements. Therefore, the identification, assessment, and control of evaporation processes in GTL fuels is considered an urgent scientific and practical problem [1,2].

Since the production technology of GTL fuels is complex and capital-intensive, their cost is relatively high. From this perspective, even minor evaporative losses during storage and transportation can significantly affect overall economic efficiency. In particular, in large storage tanks and long-distance transport processes, these losses accumulate and can cause substantial financial damage to energy enterprises and transport companies. Therefore, modeling evaporation processes, identifying losses, and developing effective strategies to minimize them are among the key tasks in the energy sector [3].

The scientific significance of this study lies in its systematic investigation of evaporative losses occurring during the transportation and storage of GTL fuels. The study analyzes the factors affecting the evaporation process, considering not only physical conditions—such as temperature, pressure, and air humidity—but also organizational and technological measures. Such an integrated approach enables comprehensive management of the evaporation process, minimizes losses, and improves fuel utilization efficiency. At the same time, the results of the study contribute to optimizing GTL fuel transport and storage systems, ensuring operational safety, and enhancing economic efficiency.

The primary aim of this research is to identify, assess, and develop effective measures to reduce losses caused by evaporation during the transportation and storage of GTL fuels.

Within this scope, the following scientific tasks are addressed:

- ✓ Identifying the causes of losses resulting from evaporation during the transportation and storage of GTL fuels;
- ✓ Developing methods for measuring and monitoring the evaporation process;
- ✓ Proposing technical and organizational measures to reduce losses.

The practical novelty of this study lies in its development of systematic and scientifically grounded recommendations for minimizing evaporative losses during the transportation and storage of GTL fuels. These recommendations can be applied by energy enterprises and transport companies and, in the future, will contribute to improving the safety and efficiency of fuel transport and storage.

Moreover, this research was conducted in alignment with global and local scientific sources. For example, Speight and Song provided a detailed analysis of the technological characteristics of GTL fuel production, storage, and transportation, while Matus et al. proposed strategies for assessing and minimizing evaporative losses. From this perspective, the present study aims to systematically investigate evaporative losses while integrating the economic and environmental aspects of GTL fuels [4].

Methods

The main goal of this research is to identify losses due to evaporation in the transportation and storage of GTL (Gas-to-Liquid) synthetic liquid fuels and to develop effective methods for their reduction. During the study, the physicochemical properties of GTL fuels, particularly saturated vapor pressure, fractional composition, and temperature dependency, were analyzed in depth.

The study was carried out based on the following methodological approaches:

1. Analytical and comparative methods: The evaporation characteristics of GTL synthetic fuels were compared with conventional petroleum fuels, identifying their similarities and differences. This stage made it possible to assess the physicochemical properties of the fuels and their evaporation potential.

2. Computational-analytical approach: The effects of temperature, pressure, and tank volume variations on evaporative losses during transportation and storage were evaluated using mathematical models. These models served to predict potential losses in fuel storage systems and optimize operational parameters.

3. Experimental and statistical analysis: Practical data obtained under production and operational conditions were processed to quantify evaporation losses. Using the balance method, the differences between fuel volume and mass before and after storage were analyzed. Additionally, regulatory documents and current technical standards were examined to assess their applicability to the transportation and storage conditions of GTL synthetic fuels [5].

4. Evaluation of technological solutions: Technological solutions aimed at reducing evaporative losses were systematically reviewed. Specifically, the technical and economic effectiveness of floating-roof tanks, vapor recovery units (VRUs), thermal insulation, and hermetic loading/unloading technologies was comprehensively evaluated. Based on these results, scientific and practical recommendations were developed to minimize evaporation losses during GTL fuel transportation and storage [6].

5. Empirical research: Practical observations were conducted at energy enterprises and fuel storage facilities in Uzbekistan. Changes in tank volume, fuel temperature and pressure, and evaporation rate were regularly measured. These observations were carried out over a 12-month period, enabling precise identification of losses.

6. Laboratory experiments: Research was conducted under laboratory conditions using mini-tanks and simulated transport lines. Parameters such as evaporation surface area, air temperature, and humidity were controlled, and technological measures to reduce losses were developed accordingly. The experimental results served as a basis for modeling and predictive analysis [7].

7. Monitoring and statistical analysis: Data collected during the study were analyzed using statistical methods. Average losses, variance, and discrepancies between actual and predicted values were determined, allowing evaluation of the effectiveness of the loss-reduction strategies.

8. Technical and organizational measures: Finally, practical measures were recommended based on the study results, including the use of closed and cooled storage tanks, reduction of evaporation using cover layers, sealing of transport containers, and implementation of monitoring systems. These measures enable a significant reduction in evaporation losses during the transportation and storage of GTL fuels [8].

These methodological approaches allowed the identification, assessment, and effective reduction of evaporative losses during GTL fuel transportation and storage. At the same time, the results provided a basis for developing practical recommendations for energy enterprises and transport companies.

Results

During the study, evaporative losses occurring in GTL synthetic liquid fuels during transportation and storage were determined through empirical and experimental measurements. Observations in storage tanks and laboratory experiments indicated that, in closed but non-cooled tanks, evaporation losses averaged a few percent. At the same time, cooled tanks with covers significantly reduced these losses, confirming that controlling the physical conditions of the storage environment is an effective method to minimize evaporation.

In transport processes, particularly in open or semi-open containers, evaporation-related losses were substantial. However, the use of cooling systems and sealed containers considerably reduced losses. Furthermore, transport speed, road conditions, and the use of closed containers had a significant impact on the level of fuel losses.

Based on mathematical models and laboratory experiments, the evaporation rate was evaluated under various storage and transportation conditions. The results of the study indicate that lowering the temperature in storage tanks and using cover layers significantly reduce evaporative losses. This finding confirms that controlling physical conditions and implementing thermal insulation strategies is an effective means of maintaining the stability of GTL fuels and minimizing operational losses.

Similarly, during transportation, sealing containers and using active or passive cooling systems help to substantially reduce losses. Observations from the study showed that the use of closed and cooled containers, along with transport speed and road conditions, directly affects the level of fuel loss. Therefore, optimizing transport systems and implementing insulation technologies serve to improve fuel efficiency and maximize economic benefits.

Using monitoring systems, the discrepancy between actual and predicted losses was analyzed. The results demonstrated that systematic monitoring, temperature-pressure control, and real-time tracking of storage parameters significantly enhance the efficiency of GTL fuel storage and transportation. This allows accurate prediction of losses and provides opportunities to minimize them. Such an approach not only increases economic efficiency but also contributes to environmental sustainability and transport safety.

The measures developed during the study—including cooling systems, tank cover layers, sealed transport containers, and real-time monitoring systems—were found to significantly reduce losses, proving their economic benefit. These findings form the basis for developing effective strategies to identify and minimize evaporation-related losses during the transportation and storage of GTL fuels.

The study results indicate that minimizing losses due to evaporation in the transportation and storage of GTL synthetic liquid fuels is a pressing issue, both technologically and economically. Empirical and experimental research enabled the development of practical measures to identify and minimize evaporation losses. Controlling storage tank temperature, using cover layers, and sealing transport containers were all found to significantly reduce fuel losses.

Discussion

The study also demonstrated that the level of losses is directly influenced by storage and transportation parameters such as temperature, pressure, air humidity, and transport speed. Therefore, improving the efficiency of evaporation modeling and monitoring systems, along with real-time control of these parameters, allows for accurate forecasting and reduction of losses. These findings align with advanced studies; for example, Matus et al. recommended measuring and minimizing evaporation losses in storage tanks, while Islam et al. presented conclusions on modeling the effectiveness of evaporation control in GTL fuels.

Experimental results showed that reducing storage temperature by a few degrees and maintaining tanks and reservoirs in a closed, hermetic state can reduce evaporation losses on average by 1.5–2 times. This effect is explained by the increase in saturated vapor pressure with temperature, which is consistent with studies on petroleum and synthetic fuels [8].

These results ensure high economic efficiency for energy enterprises by increasing the utilization of fuel resources, reducing operational losses, and decreasing emissions of volatile organic compounds (VOCs), thereby significantly mitigating environmental impact [10]. From this perspective, minimizing evaporation losses during fuel storage and transport is important not only economically but also environmentally.

Furthermore, international standards recommend operating storage tanks in a closed state and continuously monitoring temperature as effective and reliable methods for reducing evaporation losses [9]. Such approaches enhance the stability of GTL fuels during storage and transportation, reduce economic losses, and protect the environment.

During transportation, sealing containers and tankers, along with using active or passive cooling systems, was found to significantly reduce losses. This finding aligns with advanced scientific and practical research on calculating and minimizing evaporation losses during GTL fuel transport [10].

Maintaining stable temperature and pressure conditions is particularly important during long-distance transportation. This ensures fuel quality and significantly minimizes overall losses [11]. Moreover, using closed, sealed containers and implementing cooling systems in active or passive modes, combined with optimized transport conditions and road safety measures, allows for maximizing fuel efficiency.

Another key observation from the study is that loss reduction requires not only technical measures but also organizational approaches. Clear technological instructions for operators and technical personnel, the implementation of monitoring systems, and the development of safety protocols play an essential role in effectively managing evaporation losses.

Conclusion

Overall, this integrated approach helps reduce the economic impact of evaporation, increases fuel efficiency, and ensures the safety of storage and transportation systems. The results demonstrate that a combination of technical and organizational measures represents the most effective strategy for minimizing losses in the storage and transportation of GTL fuels.

The results indicate that an integrated approach—namely, controlling physical conditions (temperature and pressure), implementing modern monitoring and control systems, and applying organizational-technological measures in a comprehensive manner—is the most effective strategy for minimizing evaporation-related losses during the transportation and storage of GTL synthetic liquid fuels.

This approach provides multiple benefits: first, it preserves the physicochemical stability of the fuel, significantly reducing the evaporation rate; second, it decreases operational losses and ensures efficient utilization of fuel resources; and third, it enhances the reliability of technological processes while strengthening safety.

Therefore, an integrated approach not only optimizes the storage and transportation of GTL fuels from an economic perspective but also contributes to environmental sustainability and operational safety.

The results are consistent with both global and local scientific research. In particular, studies by J. G. Speight have shown that controlling evaporation rates and implementing monitoring systems during the storage of GTL and petroleum-based liquid fuels reduces fuel losses while ensuring high economic efficiency [1].

Furthermore, research by Song and co-authors has highlighted the critical role of automated monitoring systems in reducing evaporation losses during the transportation and storage of GTL fuels [12]. These studies confirm the effectiveness of maintaining fuel quality, minimizing operational losses, and enhancing safety in transport and storage operations.

At the same time, these scientific conclusions strengthen the reliability of the research results and serve as a foundation for developing practical strategies for the storage and transportation of GTL fuels. This approach not only enhances economic efficiency but also ensures environmental sustainability and transport safety.

The study also found that implementing loss-reduction strategies is important not only from an economic standpoint but also for ensuring ecological sustainability. The results provide a basis for developing practical recommendations to optimize the transportation and storage of GTL fuels and serve as a foundation for future research in this field.

Overall, the study demonstrates that an integrated approach to identifying, monitoring, and reducing evaporation-related losses during the transportation and storage of GTL synthetic fuels not only improves economic efficiency but also ensures the safety of storage and transport systems and strengthens environmental sustainability.

This integrated approach offers the following advantages:

1. Improved economic efficiency: Enhances fuel resource utilization, reduces operational losses, and significantly lowers operating costs.

2. Enhanced safety: Monitoring systems, temperature and pressure control, and technological protocols help prevent emergencies during storage and transport operations.

3. Environmental sustainability: Evaporation losses and volatile organic compound (VOC) emissions are reduced, significantly mitigating negative environmental impacts.

Thus, the integrated approach provides an effective and practically reliable strategy for managing losses during the transportation and storage of GTL fuels. This strategy delivers benefits not only to energy companies but also to the broader transport and environmental systems.

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