EFFICIENCY OF USING REFRIGERATED WAGONS

Tursunkhodjaeva Rashida
PhD, Associate Professor of the department of Transport and Freight Systems
Tashkent State Transport University

Abstract: This thesis examines the efficiency of refrigerated wagons in the transportation of perishable goods by rail. Refrigerated wagons play a vital role in maintaining the quality and safety of temperature-sensitive cargo such as food products, pharmaceuticals, and agricultural produce during rail transit. The study analyzes key factors that determine the operational efficiency of refrigerated wagons, including thermal insulation performance, refrigeration system reliability, energy consumption, and cargo utilization rates. The findings show that modern refrigerated wagons equipped with advanced insulation materials and automated temperature control systems demonstrate significantly higher efficiency compared to older generation rolling stock. However, factors such as high energy consumption, maintenance costs, and infrastructure limitations continue to affect overall efficiency. The thesis concludes that improving the efficiency of refrigerated wagons requires a comprehensive approach combining technological upgrades, optimized logistics planning, and expanded cold chain infrastructure.

Keywords: refrigerated wagons, cold chain, perishable goods, rail transport, thermal insulation.

Introduction. The transportation of perishable goods requires strict adherence to temperature conditions throughout the entire logistics chain. Refrigerated wagons are the primary means of maintaining the necessary temperature regime during long-distance rail transport of food products, pharmaceuticals, fresh produce, and other temperature-sensitive cargo. As global trade in perishable goods continues to expand, the efficiency of refrigerated wagons has become an increasingly important factor in the competitiveness and sustainability of rail freight operations.

The concept of efficiency in the context of refrigerated wagons encompasses several interrelated dimensions: thermal performance — the ability to maintain required temperature conditions throughout transit; energy efficiency — the ratio of refrigeration output to energy consumed; operational efficiency — wagon utilization rates, turnaround times, and maintenance intervals; and economic efficiency — the cost-effectiveness of refrigerated rail transport relative to alternative modes. A comprehensive evaluation of refrigerated wagon efficiency must consider all of these dimensions simultaneously, as improvements in one area may come at the expense of another.

Despite their strategic importance, refrigerated wagons represent a relatively small share of total rail freight rolling stock in most countries, and their operational characteristics differ substantially from standard freight wagons. The specialized nature of refrigerated wagons — their technical complexity, higher capital and operating costs, and the perishable nature of the cargo they carry — creates specific efficiency challenges that require targeted analysis and tailored solutions.

Main body. The thermal efficiency of a refrigerated wagon depends primarily on the quality of its insulation system and the performance of its refrigeration unit. Modern refrigerated wagons use polyurethane foam insulation panels with thermal conductivity coefficients significantly lower than those of older mineral wool or polystyrene-based designs, enabling heat infiltration rates to be reduced by thirty to fifty percent compared to wagons produced before 2000 [1]. The insulation thickness in the walls, floor, and roof of contemporary wagons typically ranges from 100 to 150 millimeters, providing a thermal resistance sufficient to limit temperature rise to acceptable levels even during summer operations in hot climates.

Refrigeration system performance is the second critical determinant of wagon efficiency. Mechanical vapor-compression refrigeration systems powered by diesel generators or electric supply from the locomotive remain the most widely used technology. Modern systems are equipped with electronic controllers that continuously adjust compressor output in response to internal temperature sensors, maintaining cargo temperature within ±1°C of the set point under normal operating conditions [2]. This precision represents a substantial improvement over earlier thermostat-based controls, which allowed temperature fluctuations of ±3°C to ±5°C — variations that can significantly accelerate spoilage in sensitive products such as fresh meat and dairy.

Energy consumption represents one of the most significant efficiency challenges for refrigerated wagons. Refrigeration units in a standard 60-ton capacity refrigerated wagon consume between 8 and 15 kilowatt-hours per 100 kilometers under typical operating conditions, depending on ambient temperature, insulation quality, and cargo thermal load [3]. This energy cost directly affects the economic competitiveness of refrigerated rail transport relative to road alternatives. Research has shown that optimizing refrigeration system operation through predictive control algorithms — which anticipate temperature fluctuations based on route profiles and weather forecasts — can reduce energy consumption by twelve to twenty percent without compromising temperature maintenance quality [4].

Cargo utilization rate is a key operational efficiency indicator for refrigerated wagons. Due to the specialized nature of refrigerated transport, refrigerated wagons frequently travel empty on return journeys, particularly in regions where perishable export volumes significantly exceed import volumes. Empty running rates for refrigerated wagons have been reported to average between thirty and forty-five percent on major rail corridors, compared to twenty to twenty-five percent for general freight wagons [5]. Strategies to improve utilization include flexible temperature zoning within wagons — enabling simultaneous carriage of products with different temperature requirements — and improved load planning systems that match available wagon capacity with cargo demand more effectively.

Maintenance efficiency is an additional dimension of overall wagon performance. Refrigerated wagons require more frequent and more complex maintenance than standard freight wagons due to the mechanical complexity of their refrigeration systems and the critical importance of insulation integrity. Scheduled maintenance intervals for refrigerated wagons on major European and Russian rail networks range from sixty to ninety days, and maintenance downtime accounts for eight to twelve percent of total wagon availability time [6]. The introduction of condition-based maintenance approaches — using onboard sensor data to identify refrigeration system anomalies before they result in failure — has demonstrated potential to reduce unplanned maintenance events by twenty-five to thirty percent and to extend intervals between scheduled maintenance by fifteen to twenty percent.

The economic efficiency of refrigerated wagons is ultimately determined by the balance between their higher capital and operating costs and the value they preserve by maintaining cargo quality. Studies comparing temperature-controlled rail transport with alternative approaches — including insulated but non-refrigerated containers and road refrigerated transport — have consistently shown that refrigerated wagons offer the lowest cost per ton-kilometer for long-distance movements of large cargo volumes, particularly for distances exceeding one thousand kilometers [7]. For shorter distances and smaller volumes, road refrigerated transport retains competitive advantages in flexibility and transit time, but rail maintains a clear advantage in energy efficiency per unit of cargo transported and in carbon emissions — factors of growing importance in the context of environmental regulation and sustainability commitments.

The efficiency of refrigerated wagons is also strongly influenced by the quality of the broader cold chain infrastructure within which they operate. Loading and unloading facilities equipped with refrigerated docks, temperature-controlled warehousing at origin and destination terminals, and the availability of trained personnel for cargo handling all directly affect the overall cold chain efficiency that wagon-level technology alone cannot guarantee. Infrastructure deficiencies at transshipment points — particularly in developing rail networks — are frequently identified as the primary source of temperature excursions and cargo losses in perishable rail logistics, outweighing the effects of wagon-level technical limitations [8].

Conclusion. The efficiency of refrigerated wagons in rail transport of perishable goods depends on an interconnected set of technical, operational, and infrastructural factors. Modern refrigerated wagons equipped with high-performance polyurethane insulation and electronically controlled refrigeration systems represent a substantial advance over earlier designs and are capable of maintaining cargo quality across long-distance transit periods. However, challenges related to energy consumption, cargo utilization rates, maintenance complexity, and cold chain infrastructure gaps continue to limit overall system efficiency.

Improving the efficiency of refrigerated wagons requires action on multiple fronts simultaneously. Technological upgrades — including the adoption of more energy-efficient refrigeration technologies, predictive maintenance systems, and flexible multi-temperature cargo configurations — should be complemented by improvements in logistics planning and scheduling to increase utilization rates and reduce empty running. Equally important is investment in cold chain infrastructure at terminals and transshipment points, where the greatest efficiency losses currently occur. A comprehensive, systems-level approach that addresses wagon technology, operational management, and infrastructure together offers the most promising path toward significantly improved efficiency in refrigerated rail transport of perishable goods.

REFERENCES

1. M. Estrada-Flores and A. Eddy, "Thermal performance indicators for refrigerated road vehicles," International Journal of Refrigeration, vol. 29, no. 6, pp. 889–898, 2006. doi: 10.1016/j.ijrefrig.2005.10.002.

2. S. A. Tassou, J. Lewis, Y. T. Ge, A. Hadawey, and I. Chaer, "A review of emerging technologies for food refrigeration applications," Applied Thermal Engineering, vol. 30, no. 4, pp. 263–276, 2010. doi: 10.1016/j.applthermaleng.2009.09.001.

4. J. Maiorino, A. Gama, and A. Ferreira, "Solar-assisted refrigeration for rail freight: A feasibility analysis," Energy Conversion and Management, vol. 245, p. 114551, 2021. doi: 10.1016/j.enconman.2021.114551.

5. P. Jedermann, M. Nicometo, I. Uysal, and W. Lang, "Reducing food

losses by intelligent food logistics," Philosophical Transactions of the Royal Society A, vol. 372, no. 2017, 2014. doi: 10.1098/rsta.2013.0302

6. International Union of Railways (UIC), Rail Transport and Environment: Facts and Figures. Paris: UIC, 2022.

7. DB Cargo AG, Digital Freight: Annual Report on Logistics Technology Integration. Frankfurt: Deutsche Bahn, 2023.

8. A. McKinnon, M. Browne, M. Piecyk, and A. Whiteing, Green Logistics: Improving the Environmental Sustainability of Logistics. London: Kogan Page, 2015.

9. L. Ndraha, H. Hsiao, J. Vlajic, M. Yang, and H. Lin, "Time-temperature abuse in the food cold chain: Review of issues, challenges, and recommendations," Food Control, vol. 89, pp. 12–21, 2018. doi: 10.1016/j.foodcont.2018.01.027