

# Simulation Study on the Effects of Stacking Arrangements of Railway Hazardous Material Containers on Temperature Distribution under Strong Solar Radiation

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**Abstract:** This paper addresses the safety concerns of railway hazardous material transportation under the conditions of intense solar radiation and complex geographical climate in Northwest China. Using a standard 20-foot general-purpose container as the research subject, this study employs SolidWorks for 3D modeling and Fluent for simulation to investigate the impact of different stacking arrangements on the internal temperature distribution of cargo. Based on solar radiation (S2S) and turbulence models, and setting the summer environmental conditions of the Golmud region as the simulation scenario, the temperature field variations under monolithic (single-block) and bipartite (two-block) stacking arrangements are compared and analyzed. The results indicate that under strong solar radiation, the monolithic stacking method, due to poor air circulation, tends to cause heat accumulation leading to localized high-temperature zones. In contrast, the bipartite stacking arrangement effectively promotes more uniform temperature distribution by enhancing air flow, thereby reducing the risk of localized overheating. The simulation further suggests that leaving appropriate gaps between cargo stacks, controlling stacking height, and avoiding direct placement against sun-exposed container walls can improve heat transfer and prevent heat buildup. This study provides theoretical guidance and a practical reference for optimizing stacking strategies and thermal management in railway hazardous goods transportation, particularly in high-altitude and high solar radiation regions.

**Keywords:** Northwest China; Solar Radiation; Simulation; Stacking Arrangements.

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## 1. Introduction

Western China is characterized by its vast territory and a terraced geographical pattern, dominated by the Qinghai-Tibet Plateau, inland basins of the Northwest, and mountainous regions of the Southwest, forming a macro-topography often described as "three mountain ranges flanking two basins." The region features an arid climate, scarce precipitation, intense evaporation, a sparse river network largely dependent on glacial meltwater, and fragile ecosystems. Its landscape is primarily composed of gobi (gravel deserts), deserts, and loess gullies.

In recent years, impacted by climate change, accelerated glacial retreat and permafrost degradation have heightened risks such as land desertification and grassland degradation, posing severe challenges to regional sustainable development.

Concurrently, with economic growth, the efficiency of the railway transportation industry has improved significantly, leading to increasing demand in the sector of hazardous materials transportation. However, due to their hazardous nature, the transport of such goods faces multiple constraints, and conventional container shipping often falls short of meeting current requirements. Under the extreme climatic and complex environmental conditions of Western China, railway hazardous materials transport is subjected to a dual challenge: volatile external environments and heightened safety risks.

Therefore, systematically investigating the impact mechanisms of extreme environments on the safety of railway hazardous goods transportation, and enhancing its transport

efficiency and adaptability, has become a crucial and urgent research direction requiring in-depth exploration.

## 2. Literature References

Stacking arrangement is a critical factor affecting the airflow organization and temperature uniformity inside containers. Jiang Zhimo [1], considering the technical specifications for loading a 20-foot container, conducted simulations on power lithium-ion battery cargo under different loading schemes to study the impact of stacking height and method on heat transfer. Guo Zhipeng et al. [2], considering air convection heat transfer and external heat transfer to the container, concluded that leaving certain gaps in the middle of the cargo can effectively improve heat exchange, leading to a more uniform and overall higher temperature inside the container. Tian Jinjin et al. [3], using a refrigerated container, found that gaps between cargo units alter the flow field distribution, intensifying heat convection and affecting the temperature field. Zhao Chunjiang et al. [4], through temperature field analysis, discovered that different cooling air velocities and cargo stacking methods significantly impact the internal temperature of the compartment, the surface temperature of the cargo, and the depth of cooling air influence on the goods.

Leonardo Junqueira, Reinaldo Morabito et al. [5] established a three-dimensional container loading model and a mixed-integer linear programming model based on the principles of cargo stability and load-bearing constraints. Their work analyzed cargo stability in both longitudinal and lateral directions, as well as cargo loading strength (including fragility), ultimately proposing an effective reinforcement

model. David Pisinger [6] proposed that the container loading problem can be analogized to a knapsack problem. Based on a heuristic algorithm that decomposes the problem into several layers, the solution to the container capacity problem was ultimately approached by considering the container's width and height. Using a branch and bound method to explore subsets at each node branch, corresponding algorithm examples were provided, and comparisons were made between isomorphic and heterogeneous models.

Yang Nan and Yin Qianwei [7] conducted a systematic study on the temperature field of general-purpose containers under the special climatic conditions of plateau regions. They found that due to the high intensity of solar radiation, thin air, and weakened convective heat transfer capacity in plateau areas, the container surface is prone to significant non-uniform heat accumulation. This effect is most prominent in areas with prolonged direct sunlight exposure, such as the upper roof surface, where local high-temperature effects are most pronounced. This surface heat accumulation can be transferred to the interior through the container structure, posing a direct threat to the safety status of temperature-sensitive hazardous goods.

### 3. Physical Model Construction

This study investigates the transportation of hazardous materials using standard intermodal containers, with a standard 20-foot general-purpose container as the research subject. According to international standards, the external dimensions of the 20-foot container are 6058 mm × 2438 mm × 2591 mm, and its internal dimensions are 5898 mm × 2352 mm × 2393 mm. The container body is constructed from weathering steel.

The internal cargo is uniformly packaged in standard wooden crates with a density of 540 kg/m<sup>3</sup>, a specific heat capacity of 1720 J/(kg·°C), and a thermal conductivity of 0.3 W/(m·°C). Two stacking arrangements are employed: monolithic stacking and bipartite stacking.

The model was constructed using SolidWorks and subsequently imported into ANSYS Fluent for meshing. The average mesh element quality achieved was 0.6, indicating excellent mesh quality. An external cavity shell was added around the entire model to serve as the external flow domain for the simulation.

The simulation utilized the Surface-to-Surface (S2S) radiation model for solar radiation and a turbulence model for air convection(k-epsilon). The calculation commenced with solar radiation conditions corresponding to 8:00 AM. The simulated geographical location was Golmud, with coordinates set at longitude 94.89° and latitude 36.42°.

### 4. Mathematical Model Construction

Governing Equation for Heat Conduction:

$$q = -\lambda \cdot \nabla T \quad (1)$$

Newton's Law of Cooling: Convective Heat Transfer

$$\varphi = \alpha(t_f - t_w)F \quad (2)$$

Thermal Radiation:

Thermal radiation is a mode of energy transfer via electromagnetic waves. This form of heat transfer covers a specific portion of the electromagnetic spectrum, with wavelengths ranging from 0.1 to 100 micrometers. For semi-transparent media (such as glass or combustion product gases),

radiation is a volumetric phenomenon because radiation energy can escape from within the bulk of the material itself. For opaque objects, radiation is predominantly a surface phenomenon because nearly all internal radiation is absorbed within the material before it can escape.

$$q_{rad} = \sigma \varepsilon (T_{max}^4 - T_{min}^4) \quad (3)$$

$$q_{conv} = h(T_{wall} - T_{bulk}) \quad (4)$$

### 5. Boundary Condition Setup

The working fluid was air at 20°C with a density of 1.204 kg/m<sup>3</sup>. Based on the standard summer morning (8:00 AM) temperature for the Golmud region, the ambient temperature surrounding the container was set to 20°C. The heat transfer coefficient between the container exterior and the ambient environment was defined as 0.32 W/(m<sup>2</sup>·°C).

For turbulence modeling, the values of turbulent kinetic energy and turbulent dissipation rate ( $\varepsilon$ ) were determined using the scalable wall function approach. The specific k- $\varepsilon$  model employed was the Realizable k- $\varepsilon$  model.

For viscous flow, a no-slip boundary condition was applied to all walls. The following assumptions were made:

1. The air inside the container was treated as an incompressible fluid satisfying the Boussinesq approximation.
2. All internal cargo was considered solid, with no internal heat generation.
3. Thermal radiation between the container walls and the cargo surfaces was neglected.

At the inlet boundary of the external cavity surrounding the container, an airflow direction was specified. The inlet air temperature was set to 20°C with an inflow velocity of 0 m/s, simulating natural convection conditions. The outlet temperature was set equal to the inlet temperature.

A gravitational acceleration of 9.81 m/s<sup>2</sup> was applied in the negative Y-axis direction.

For both cargo stacking arrangements, the temperature observation points were located at the center point of the sun-exposed surface.

### 6. Simulation Results and Analysis

The simulation was conducted from 08:00 to 20:00, with the peak temperature occurring at approximately 15:00. Utilizing a solar tracking model, it was visually confirmed that the temperature of the sun-exposed wall surfaces increased rapidly, significantly impacting the internal cargo. This led to heat accumulation in the upper sections, creating a substantial temperature differential between the upper and lower regions.

The internal temperature distribution of the cargo varied significantly between the two stacking arrangements. The monolithic stacking method, due to its restricted internal air circulation, facilitated significant heat accumulation, resulting in localized high-temperature zones. Conversely, the bipartite stacking arrangement enhanced internal airflow, promoting more uniform temperature distribution. This configuration effectively prevented localized hotspots by enabling heat dissipation across different areas, achieving a more averaged temperature profile.

The simulation analysis concludes that when transporting goods sensitive to temperature, a dispersed stacking strategy is preferable to concentrated stacking. Leaving adequate gaps between cargo units prevents detrimental heat buildup. Furthermore, controlling stacking height and positioning cargo away from directly sun-exposed walls can reduce

conductive heat transfer, thereby providing better thermal protection for the goods.

As clearly illustrated in Figure 1, the simulation data demonstrates that the bipartite stacking method results in a more gradual and balanced temperature increase within the cargo, whereas the monolithic stacking method leads to more abrupt and extreme temperature fluctuations.

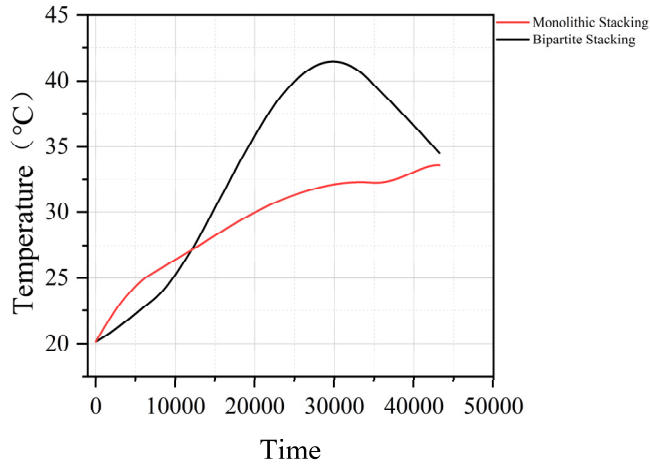


Fig 1. Temperature Curve Chart for Different Stacking Arrangements

## 7. Conclusion

To investigate the impact of different stacking arrangements on containers and their cargo, a standard 20-foot general-purpose container was used as a case study for simulation analysis via Fluent software. The analysis focused on the effects of solar radiation on cargo temperature under various stacking methods in the high-altitude western regions. The findings indicate that when transporting temperature-sensitive goods in plateau areas, careful attention must be paid to the stacking method. Sufficient gaps should be maintained

between cargo units during stowage to prevent heat accumulation. Additionally, the distance between the cargo and the sun-exposed container walls should be controlled to minimize damage caused by localized high temperatures.

## Acknowledgments

Science and Technology Research and Development Project of China State Railway Group Co., Ltd(N2020X021).

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