Applied Science and Innovative Research
ISSN 2474-4972 (Print) ISSN 2474-4980 (Online)
Vol. 10, No. 2, 2026
www.scholink.org/ojs/index.php/asir

Original Paper

Optimal Design of Fire Water Supply System for Automated Storage/Retrieval System of Automotive Rubber Product

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Received: May 8, 2026   Accepted: May 29, 2026   Online Published: June 9, 2026

doi:10.22158/asir.v10n2p39   URL: http://dx.doi.org/10.22158/asir.v10n2p39

Abstract

Automated storage/retrieval systems for automotive rubber products usually have large racks and high storage density. Rubber products have dangerous characteristics such as high combustion calorific value, large amounts of smoke, and rapid fire spread. Once a fire occurs, it will cause serious casualties and property losses. At present, domestic fire protection design specifications for automated storage/retrieval systems of automotive rubber products are not yet complete, and systematic technical guidance is insufficient. In actual projects, there are common problems such as difficult system selection, complex pipeline laying, and difficult hydraulic calculations. Focusing on the above issues, this article focuses on discussing the main technical bottlenecks and their causes in the design of fire water supply systems, and proposes corresponding optimization strategies and solutions, in order to provide a reference for the formulation of fire protection plans, construction drawing design and engineering practice for similar projects in the future.

Keywords

Automated storage/retrieval system, Rubber product, Fire protection design, Water supply system

1. Introduction

In recent years, with the continuous upgrading of the automobile industry and the deep penetration of intelligent manufacturing technology, the automotive rubber product manufacturing industry is accelerating its transformation towards automation and integration. (Pradeep and Balaji, 2022; Wang et al., 2025) As a key node in the supply chain system, automated three-dimensional warehouses for automotive rubber products play an increasingly important role in improving warehousing efficiency and material management levels. This type of warehouse relies on new generation information technologies such as the Internet of Things, 5G communications, and digital twins, combined with automatic guided vehicles (AGVs), smart shuttles, and high-density racking systems. Through deep integration with warehouse management systems (WMS), warehouse control systems (WCS), and enterprise resource planning (ERP) systems, it has achieved a doubling of access efficiency and visual management and control of the warehousing process. (Azadeh et al., 2019; Borovinšek et al., 2021) However, as the scale and storage density of warehouses continue to expand, the complexity and challenges faced by the design of their fire water supply and drainage systems have become increasingly prominent.

In the special application scenario of automotive rubber products, AS/RS present significant risk characteristics and technical difficulties. Take the three-dimensional warehouse of a certain automotive rubber products company as an example. It uses an ultra-high-rise racking system, and the storage density is far higher than that of traditional flat warehouses. However, it also brings more severe fire safety hazards: rubber products themselves have the characteristics of high combustion calorific value, large smoke volume, and relatively low ignition point. Once a fire occurs, the fire spreads rapidly; the continuous operation of automated equipment may produce mechanical sparks or electrical failures; dense stacking structures can easily form vertical ventilation channels similar to “chimneys”, accelerating the upward spread of flames and hot smoke. (Trapp and Rangwala, 2015; Butean et al., 2025) In addition, the three-dimensional warehouse for automotive rubber products is an emerging facility that has been rapidly promoted in recent years. Currently, there are no fully applicable fire water supply and drainage design specifications in China. In design practice, there are common problems such as complex fire pipeline laying, difficult construction, and difficulty in unifying system selection and water source guarantee.

Based on the above realistic background, this article conducts a systematic analysis of the main problems existing in the fire water supply and drainage design of the automated three-dimensional warehouse for automotive rubber products, discusses its causes and potential risks, and proposes corresponding optimization and improvement measures, with a view to providing a reference for the plan formulation, construction drawing design and engineering practice of similar projects.

2. Problem Description and Analysis

2.1 Composition of AS/RS

An Automated Storage/Retrieval System (AS/RS) is a highly efficient warehousing system that utilizes high-rise racks to store goods and employs automated equipment to handle storage, retrieval, material handling, and information management. It offers numerous advantages, including high space utilization, conservation of land resources, high warehousing and logistics efficiency, and low cargo handling and storage losses, as shown in Figure 1. However, due to the high concentration of stored goods, firefighting efforts are challenging. If a fire is not effectively controlled in its early stages, it can easily result in severe losses; therefore, the fire protection water supply and drainage system must meet higher standards.

Figure 1. AS/RS Application Scenario

The AS/RS is mainly composed of the following 7 key elements:

(1) Rack system: As the physical basis for storing goods, it is usually constructed of steel and is divided into two types—welded and modular—to support and store goods.

(2) Carrying units: These are pallets or bins used to load and secure goods, facilitating mechanized handling and storage.

(3) Lane stacking equipment: This is the core operating machinery in the AS/RS. It can move in the lanes between racks to realize automatic access to goods. There are many types according to different structures and service methods. (Yan et al., 2023; Xu et al., 2024)

(4) Conveyor system: Including various conveyors, such as rollers, chains, lifting tables, etc., which are responsible for transporting goods from one area of the warehouse to another, especially for docking with lane stackers. (Karami et al., 2022; Majumder et al., 2024)

(5) Automated guided vehicle (AGV) system: This is a vehicle that can navigate and move autonomously in the warehouse. It is used for the transportation and transfer of goods. According to different navigation methods, it is divided into induction type and laser-guided type. (Li et al., 2022; Lin et al., 2023)

(6) Warehouse control system (WCS): This is the “nerve center” of the AS/RS, responsible for coordinating and controlling the operation of various equipment to ensure the smoothness and efficiency of the entire system.

(7) Warehouse management system (WMS): As the “brain” of the warehouse, WMS is responsible for processing and managing all information related to goods storage, retrieval, inventory, etc., and can be integrated with other enterprise systems (such as ERP) to achieve data sharing and exchange.

2.2 Analysis of Fire Water Supply in AS/RS

The main construction contents of an automotive rubber products industrial park include a rubber mixing workshop, a vulcanization workshop, a finished product testing area, a raw material and finished product storage area, and an elevated AS/RS. The system integrates full-process operations such as temporary storage of finished products, automatic palletizing, pre-processing and warehousing, high-density storage, intelligent tallying and automatic outbound operations. After the rubber products are vulcanized and tested on the production line, they are automatically transferred to the warehouse through the conveyor belt system, realizing fully automated operations from storage to storage. Each functional unit is connected by a conveyor belt. There are conveyor openings on the firewall between different fire protection zones, and fireproof roller shutters are installed to ensure zone isolation under fire conditions. The main structure of the AS/RS is a high-rise rack storage unit with a total height of approximately 30 m, which is divided into 2 independent fire protection zones. Each partition is equipped with 10–12 rows of racks, arranged in a combination of single and double rows. Each row of racks is divided into 12–14 layers of partitions, with a layer spacing of about 2.0–2.1 m. The rack unit size is designed according to the packaging specifications of rubber products, and is suitable for storing various types of automotive sealing strips, hoses, shock-absorbing parts and other rubber products.

The industrial park has been equipped with a complete stable and high-pressure fire water supply system. The maximum fire water supply flow is 450 L/s, the water supply pressure is not less than 1.2 MPa, and the fire water storage capacity is 10,000 m^3. There are DN400mm annular buried fire water supply pipes laid in the factory area, which can meet the fire water demand of this project. In view of the fire hazard characteristics of rubber products such as high combustion calorific value and large amount of smoke, the design of the fire water supply and drainage system of automated three-dimensional warehouses needs to focus on special measures such as rapid fire extinguishing, smoke prevention and fire prevention, and pipeline laying optimization. In addition, the fire protection facilities and fire water consumption set up in different internal areas are also quite different. The specific situation is shown in Table 1.

Table 1. Firefighting Facilities and Water Consumption in Various Areas of AS/RS

Area name	Firefighting facilitie	Fire water consumption/(L/s)	Duration of the Fire/h	Total volume of water/m^3
Outside the building	Outdoor fire hydrant	45	3	468
Packaging area	Indoor fire hydrant	10	3	108
	Fire water curtain	12.73	4	183
Preprocessing Area	Indoor fire hydrant	10	3	108
	Fire water curtain	45.82	3	495
Elevated Warehouse	Self-spraying system	52 (Top) 35 (Rack)	2 (Top) 1 (Rack)	501

	Remote control water cannon	60	1	
	Fire water curtain	26.31	3	
	Indoor fire hydrant	10	3	108
Tally area	Fire water curtain	18.67	3	202
	Remote control water cannon	60	1	216
Staging area	Indoor fire hydrant	10	3	108

3. Fire Protection System Design

3.1 Outdoor Fire Hydrant Water Supply System

The overall building of the automated three-dimensional warehouse for rubber products for vehicles is classified as a Category C warehouse. According to the relevant provisions of the "Code for Fire Protection Design of Buildings" (GB50016), its outdoor fire-fighting water consumption is designed to be 45 L/s, the fire duration is 3 hours, and the total outdoor fire-fighting water consumption for one fire extinguishing is 486 m^3.

The factory has built a complete stable and high-pressure fire water supply system, and a DN400mm ring fire pipe network is laid outdoors. The outdoor fire-fighting water of the warehouse is connected to two independent fire-fighting water supply pipes through the ring fire pipe network. When any one of the water inlet pipes fails, the remaining water inlet pipes can still meet the total outdoor fire-fighting water supply requirements. Several SSFT100-1.6 pressure reducing and stabilizing anti-collision fire hydrants are installed on the outdoor fire pipe network, and are equipped with special outdoor fire hydrant boxes. Fire hydrants are generally arranged along the roadside, about 1m away from the roadside, and the distance between fire hydrants is controlled to no more than 120m. The fire ring pipe network is set up in sections with valves, and the number of outdoor fire hydrants in each independent pipe section does not exceed 5, which facilitates inspection and maintenance.

Considering that there is a high-level silo on the top of the packaging area of the AS/RS for automotive rubber products or the adjacent production area (used for the temporary storage of rubber raw materials or semi-finished products, with a height of about 35–42m), it is difficult for the water gun jet of conventional outdoor fire hydrants to effectively cover this high-level area. For this reason, the design considered using the fire-fighting water cannons already installed in adjacent workshops or process equipment areas as supplementary fire-fighting facilities to protect the high-level silos of the warehouse to make up for the lack of vertical coverage of the outdoor fire hydrant system.

3.2 Indoor Fire Hydrant System

The packaging workshop, tallying area and other areas in the automated three-dimensional warehouse for automotive rubber products are all designed as Category C workshops. The indoor fire hydrant adopts a pressure reducing and stabilizing fire hydrant, equipped with a 19 mm water nozzle and a 25 m long water hose. The layout of fire hydrants shall meet the following requirements: at any part of the same floor in each fire protection zone, the full water column of at least 2 water guns will arrive at the same time. The indoor fire water supply pipes are arranged in a ring, and the fire ring network is equipped with two water inlet pipes connected to the outdoor fire pipe network or fire water pumps. The indoor fire water supply pipeline is divided into several independent sections using valves. The valve settings should ensure that the number of fire hydrants out of service for maintenance does not exceed 5.

The main body of the automatic warehouse, the high-bay warehouse, is completely mechanized and personnel cannot enter the racks under normal circumstances. Therefore, fire-extinguishing facilities such as indoor fire hydrants and fire extinguishers that require manual operation cannot function in the rack area. In addition, the maximum height of a single floor of an elevated warehouse is 30m. According to the calculation formula for filling the water column of indoor fire hydrants in the "Code for Fire Protection Design of Buildings" (GB50016):

$$S_k = \frac{H-1}{\sin\alpha} \tag{1}$$

In the formula: *H*—floor height, m; *α*—upward inclination angle of the water gun, taking the upper limit of 60°.

After calculation, the required full water column length is about 33.5–35.8 m. The resulting fire hydrant nozzle pressure is far more than 0.5 MPa, making it difficult for firefighting professionals to operate safely and effectively extinguish the fire.

Based on the above reasons, after communicating with the fire protection department and the construction drawing review unit, it was confirmed that fire hydrants and fire extinguishers were not installed inside the racks. However, at the parts where the front and rear ends of the elevated warehouse are connected to other functional areas (such as the packaging workshop, tallying area, outbound area, etc.), personnel can enter and have a certain space for operating activities. Therefore, a number of indoor fire hydrants and fire extinguishers are installed in the local areas accessible to these personnel, mainly used to extinguish sporadic initial fires that may occur on the maintenance platform, near the ground area and around the equipment.

4. Automatic Sprinkler System Design

The automatic sprinkler system is the most important and important component of fire protection in AS/RSs. The type and fire risk level of the automatic sprinkler system should be determined based on the architectural characteristics, environmental conditions and fire characteristics of the setting place. For warehouses, the system design parameters should be determined based on fire risk level 6, storage method, maximum clearance height, maximum storage height, sprinkler head selection, etc. The three commonly used sprinkler head selection conditions are shown in Table 2.

Table 2. Selection Conditions for Commonly Used Nozzles in Warehouses

Nozzle type	Early suppression fast response sprinkler head	Warehouse type special application nozzles	Standard coverage area sprinkler heads
Maximum headroom	h≤13.5m	h≤12m	1. Headroom h≤9m 2. Headroom h＞9m
Setting location	Top plate	Top plate	1. Top plate 2. Top plate + inside rack

Since the clearance height and storage height of the above-mentioned automated three-dimensional warehouse exceed the maximum height allowed by early suppression rapid response sprinklers and warehouse-type special application sprinklers, an automatic sprinkler system is adopted that combines standard coverage area sprinklers under the roof and sprinklers in the racks. The installation of sprinkler heads in the racks makes up for the delay in the start-up time of the sprinkler heads on the top floor, and can put out the fire before it spreads on a large scale.

4.1 Roof Sprinkler System

When arranging sprinklers under the roof, according to the warehouse hazard level I, the corresponding water spray intensity is 20.0 [L/(min·m^2)], the effective area is 200 m^2, and the continuous water spray time is not less than 2 hours. According to Article 9.1.5 of the “Design Regulations for Automatic Sprinkler Systems” (GB50084), the average water spray intensity within the area enclosed by any four sprinklers within the most unfavorable point of action area should not be less than 18L/(min·m^2), thus:

$$q = K\sqrt{10P} \tag{2}$$

Among them: q is the nozzle flow rate, L/min; P is the nozzle working pressure, MPa; K is the nozzle flow coefficient.

Using a nozzle with flow coefficient K=115, if the maximum protection area of a nozzle is 9 m^2, the estimated nozzle pressure at the most unfavorable point is 0.20 MPa. At this time, the calculated flow rate of the nozzle under the roof is 90 L/s.

4.2 Rack Sprinkler System

In the design conditions, the rack height is 30 m, and each rack is 2 m. Each rack is equipped with sprinkler heads, and the distance between the built-in sprinkler head of the highest rack and the top of the storage should not exceed 3.0 m. The setting parameters of the sprinkler heads in the rack are shown in Table 3.

Table 3. Setting Parameters of In-rack Sprinklers

Hazard level	Rack built-in sprinkler open number/piece			Rack built-in standard coverage sprinkler working pressure/MPa	
	Layer 1	Layer 2	Layer 3	Flow coefficient K=80	Flow coefficient K=115
Grade I	6	12	14		
Grade II	8	14		≥0.20	≥0.10
Grade III	10	14			

The sprinkler heads in the racks adopt standard coverage area sprinkler heads with a flow coefficient K=115, the working pressure is not less than 0.10 MPa, and the water spray duration is 2 hours. The number of built-in sprinkler heads on the rack exceeds 2 floors. The number of open sprinkler heads for hazardous Class I warehouse is 14. The calculated flow rate is based on the top 2 floors. The number of open sprinkler heads on each floor is 7. The flow rate of built-in sprinkler heads on the rack is 30 L/s. The arrangement of sprinkler heads and the laying of sprinkler pipes in the racks need to be closely coordinated with the rack technology profession. The self-spraying risers and main pipes of single-row racks are laid between the racks and the wall, and the branch pipes extend into the racks. The sprinkler heads are installed directly above the cargo spaces in the racks. The self-spraying risers and main pipes of double-row racks are laid in the gap between the two rows of racks, and the sprinkler heads are installed in the gaps. See Figures 2 and 3 for the nozzle layout.

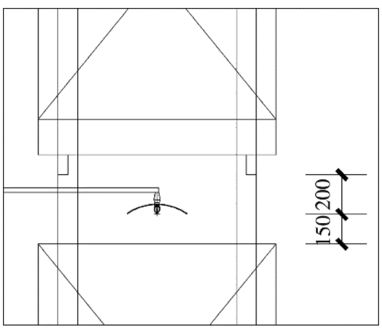

Figure 2. Single-row rack nozzle arrangement

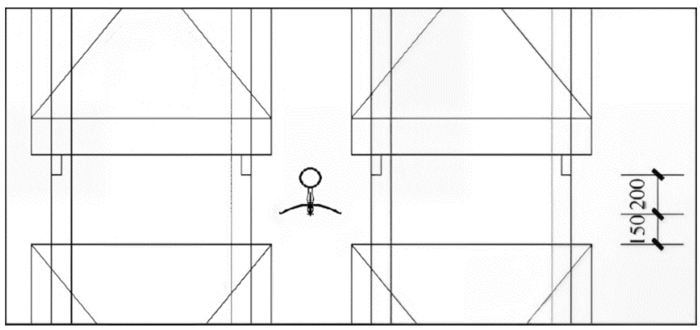

Figure 3. Double-row racks nozzle arrangement

The vertical distance between the sprinkler splash plate and the top of the goods should not be less than 150 mm. Taking into account the space occupied by the spray branch pipes and elbows, the inter-layer dimension between the goods and the upper rack should be controlled to 350 mm. The nozzle in the rack should be equipped with a heat collecting cover. The heat collecting cover should be made of a circular metal plate with an area of not less than 0.12 m^2, and the periphery should be rolled down and flush with the splash plate.

The installation of sprinkler risers between double rows of racks requires special attention to the spatial relationship between the racks. The distance between the double rows of racks in the automated three-dimensional warehouse in this article is 600 mm. The width of the stored goods exceeds the rack columns by 100 mm, and the rack back-pull supports need to occupy 100 mm of space. In addition, when the stacker stores and retrieves goods, an additional 70 mm safety margin needs to be reserved to avoid collisions between the stacker and the risers and supports. Deducting the above necessary space, the sprinkler riser needs to be installed within a 160 mm space, as shown in Figure 4. The automated three-dimensional warehouse fire water supply system designed in this article controls the number of sprinkler heads on a single riser so that the diameter of the sprinkler risers in all racks does not exceed DN100.

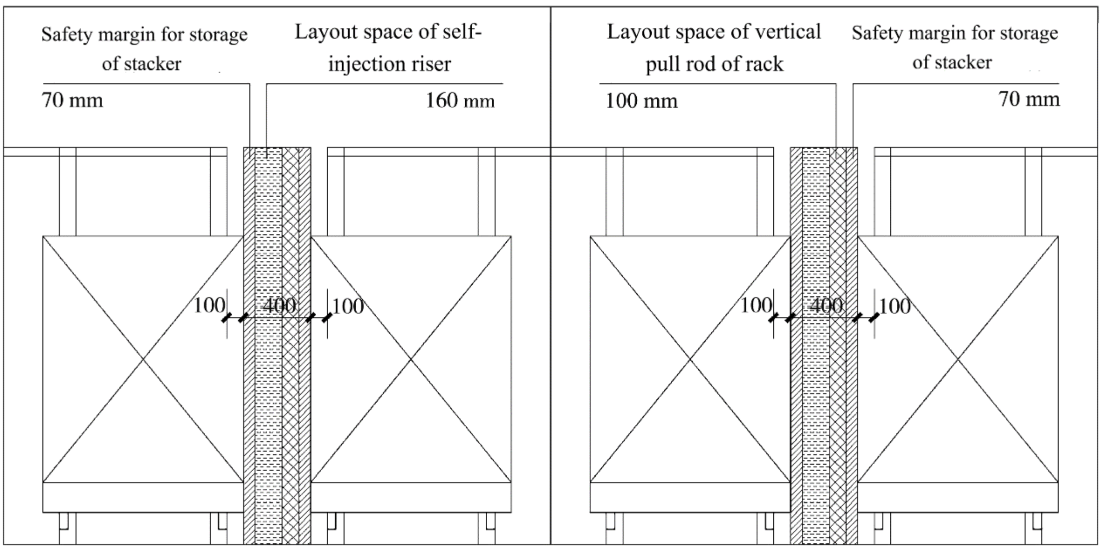

Figure 4. Spatial Relationship between Double-row Racks

5. Conclusion

Compared with ordinary warehouses, AS/RS for automotive rubber products have significant characteristics such as large building height, complex rack structures, high storage density, large fire equivalent of rubber products, and high combustion calorific value. Its special internal spatial structure is conducive to the rapid spread of fire. At the same time, it faces greater difficulties in fire detection and alarm, fire extinguishing and rescue, and the layout of fire water supply and drainage systems. At present, the fire protection design specifications for this type of new warehouse are not yet complete, and relevant technical research still needs to be further in-depth.

This paper combines the fire hazard characteristics of automotive rubber products with the engineering reality of AS/RS, focuses on analyzing the key issues in the design of fire water supply systems, and proposes corresponding optimization measures. The recommended fire extinguishing system configuration takes into account both pertinence and completeness, as well as operability and economic rationality. For other automated elevated warehouses with different forms and different storage of goods, designers should reasonably determine the fire protection design parameters, fire extinguishing system selection and pipeline laying method based on factors such as the actual warehouse layout, rack structure, cargo fire risk level, etc. In addition, during the hydraulic calculation process of the fire pipe network in complex warehouses, it is recommended to use advanced fire engineering calculation software to ensure the technical safety and economic rationality of the fire extinguishing system, and provide an effective reference for the fire water supply and drainage design of similar projects.

References

Azadeh, K., De Koster, R., & Roy, D. (2019). Robotized and automated warehouse systems: review and recent developments. *Transportation Science*, *53*(4), 917-945. https://doi.org/10.1287/trsc.2018.0873

Borovinšek, M., Ekren, B. Y., Burinskiene, A., & Lerher, T. (2021). Multi-objective optimisation model of shuttle-based automated storage and retrieval system design. *Transport*, *36*(2), 245-262.

Butean, M. A., Aschilean, I., & Felseghi, R. A. (2025). Integrated performance of sprinkler and natural smoke ventilation systems in warehouses: a cfd-based evaluation using pyrosim. *Buildings*, *15*(20), 3767. https://doi.org/10.3390/buildings15203767

Karami, F., Fathi, M., & Pardalos, P. M. (2022). Conveyor operations in distribution centers: modeling and optimization. *Optimization Letters*, *16*, 2589-2612.

Li, C., Zhang, L., & Zhang, L. (2022). A route and speed optimization model to find conflict-free routes for automated guided vehicles in large warehouses based on quick response code technology. *Advanced Engineering Informatics*, *52*, 101604. https://doi.org/10.1016/j.aei.2022.101604

Lin, S., Liu, A., & Wang, J. (2023). A dual-layer weight-leader-vicsek model for multi-agv path planning in warehouse. *Biomimetics*, *8*(7), 549. https://doi.org/10.3390/biomimetics8070549

Majumder, H. , Bachhav, R. S. , & Castaldo, P. (2024). Optimization of pallet conveyor system for weight reduction. *Journal of Engineering*, *5567309*, 19. https://doi.org/10.1155/2024/5567309

Pradeep, A., & Balaji, K. (2022). Reduction of lead time in an automobile rubber components manufacturing process through value stream mapping. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, *236*(6), 2470-2479. https://doi.org/10.1177/09544089221094094

Trapp, A. C., & Rangwala, A. S. (2015). Analyzing the impact of in-rack sprinklers in a warehouse fire: A demonstration of the role optimization has in mitigating damage. *Fire Safety Journal*, *73*, 11-22. https://doi.org/10.1016/j.firesaf.2015.03.002

Wang, L., Zhang, H., Liu, Y., et al (2025). Advanced silica networks in rubber composites for optimizing energy efficiency and performance in electric vehicle tires. *ACS Applied Polymer Materials*, *7*(4), 2731-2742. https://doi.org/10.1021/acsapm.5c00189

Xu, R., Tuo, Y. F., Chen, H. M., & Xu, J. X. (2024). Scheduling parallel cranes for unit-load automated storage and retrieval systems with shared storage. *Systems*, *12*(1), 25.

https://doi.org/10.3390/systems12010003

Yan, Q., Lu, J. S., Shao, Y. P., Xu, L., & Ren, C. H. (2023). A scheduling optimization method for stacker path in double-ended compact storage system. *Advances in Mechanical Engineering*, *15*(2), 1-14. https://doi.org/10.1177/16878132231154173