Advanced and Sustainable Technologies
ASET
E-ISSN 2976-2294
Volume 5, No 1, June 2026 [23-33]

Enhancing Process Safety in Ammonia-Based Refrigeration for The Food Industry: A Mini Review

Muhammad Najib Jaafar[1,2]*, Masli Irwan Rosli[1,4], Darman Nordin[1,4] and Hafizul Fahri Hanafi[3]

[1]Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.
[2]Department of Occupational Safety and Health Malaysia, Level 5, Setia Perkasa 4, Setia Perkasa Complex, Federal Government Administrative Centre, 62530 Putrajaya, Malaysia.
[3]Faculty of Computing and Meta-Technology, Universiti Pendidikan Sultan Idris, 35900 Tanjung Malim, Perak, Malaysia.
[4]Smart Circular Design Research Group, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.

Received 8 February 2026, Revised 5 March 2026, Accepted 12 March 2026

ABSTRACT

This mini-review evaluates sustainable technological strategies to enhance process safety and environmental performance in ammonia-based refrigeration systems in the food industry. Ammonia has zero ozone-depletion potential (ODP) and negligible global warming potential (GWP ≈ 0), supporting climate mitigation objectives aligned with the Sustainable Development Goals (SDGs) 9, 12, and 13. However, its toxicity and flammability present occupational and environmental risks that require integrated engineering and digital safety controls. A structured review of 1,568 peer-reviewed publications from Scopus, Web of Science, and Google Scholar was conducted, but only 32 publications met the criterion for empirical and review articles on enhancing process safety in ammonia-based refrigeration for the food industry. The findings indicate that IoT-enabled monitoring, real-time gas detection, automated shutdown systems, and predictive maintenance analytics reduce the likelihood of leaks, energy intensity, and operational disruptions. Low-charge ammonia systems, secondary loop configurations, and hybrid refrigeration architectures further minimize refrigerant inventory and potential Scope 1 emission exposure. Despite measurable progress, implementation barriers persist, including capital investment constraints, fragmented regulatory frameworks, and limited Environmental, Social, and Governance-based safety performance metrics. Advancing sustainable refrigeration requires harmonized standards, digitized risk governance, and quantifiable carbon-reduction indicators to achieve resilient, climate-aligned food production systems.

Keywords: Ammonia refrigeration, Operational efficiency, Risk management, Safety enhancements, Food industry.

1. INTRODUCTION

The food sector relies on ammonia-based refrigeration systems for several reasons, including maintaining food safety and product quality, and meeting the demands of the global cold chain. Ammonia (NH_3) is recognized as one of the most effective and environmentally friendly refrigerants due to its high thermodynamic efficiency and low global warming potential. It is used in large cold storage facilities, food processing plants, and refrigerated transport systems to ensure that perishable food remains safe during storage and transportation [1-3]. Ammonia plays a crucial role in maintaining food safety. It is crucial for refrigeration systems to maintain precise

*Corresponding author: narjeep@gmail.com

temperature controls to prevent food from spoiling and becoming contaminated. Temperature changes can lead to significant food waste and health risks for customers [2-4].

Utilizing modern leak detection technologies, such as the Refrigeration System Leak Detection Cloud Service (RSLDCS), can significantly enhance the ability to monitor and control leaks in ammonia refrigeration systems [5]. This method helps pinpoint leaks accurately, keeping the facility safe and maintaining high food quality. Additionally, thorough safety checks are crucial because ammonia is poisonous and poses significant risks, requiring effective risk management to protect workers and the environment [6]. It's essential to ensure that all safety rules and precautions are in place. This includes non-destructive testing and penetrating liquid tests for key steps in the process, which are essential for optimal operation and maintenance [7]. Abed and colleagues further improved the NH_3/H_2O absorption heat pump by installing an ejector between the rectifier and the condenser, as well as a refrigerant heat exchanger between the condenser and the evaporator [8]. This change was expected to improve the overall system performance by approximately 12.2% compared to the standard ammonia-water heat pump.

Process safety in the food industry is foundational to protecting consumers, ensuring regulatory compliance, and building resilient supply chains. Across the literature, a process-oriented view, anchored in systematic risk assessment, preventive controls, and continuous improvement, consistently outperforms reactive or end-point testing approaches. The ISO 22000 family, Hazard Analysis Critical Control Point (HACCP) and Prerequisite Programs (PRP), PDCA (plan, do, check and act) - driven food safety management systems (FSMS), and the integration of risk analytics and information technology all converge on a single message: proactive design, operation, verification, and improvement of processes reduce hazards, prevent contamination, and protect public health [9-11].

The goal of this brief overview is to consolidate our knowledge of process safety in ammonia-based refrigeration systems and their applications in the food industry. In particular, it aims to (1) pinpoint significant safety hazards and risk factors associated with ammonia refrigeration operations, (2) assess the efficacy of current process safety management (PSM) strategies, (3) underscore emerging technologies and best practices for accident prevention and mitigation, and (4) examine existing regulatory and implementation obstacles that hinder the widespread adoption of safety innovations. This analysis addresses critical topic areas, encompassing ammonia hazard characteristics and accident patterns, risk assessment approaches, engineering and operational safety controls, and prospective advancements in safety enhancement via digitalization and predictive maintenance.

Despite measurable progress, implementation barriers persist, including capital investment constraints, fragmented regulatory frameworks, and limited Environmental, Social, and Governance (ESG)-based safety performance metrics. Advancing sustainable refrigeration, therefore, requires harmonized safety standards, digitized risk governance frameworks, and quantifiable carbon-reduction indicators that integrate process safety management with sustainability objectives. Strengthening inherently safer design, leak prevention strategies, and real-time risk monitoring not only reduces accident probability and emission exposure but also directly contributes to SDG 9 (resilient industrial innovation), SDG 12 (responsible production systems), and SDG 13 (climate action), ensuring that food refrigeration infrastructure remains safe, low-carbon, and operationally resilient.

2. METHODOLOGY

A comprehensive literature search was conducted using three major academic databases: Scopus, Web of Science, and Google Scholar. The search aimed to identify peer-reviewed studies on the safety and risk aspects of ammonia-based industrial refrigeration systems, particularly in the food sector. The following Boolean string was applied:

(“risk assessment” OR “risk analysis” OR “risk identification” OR “risk mitigation” OR “safety issues” OR “hazard analysis” OR “accident consequence” OR “numerical study”) AND (“ammonia” OR “ammonia leakage” OR “ammonia release” OR “ammonia dispersion”) AND (“industrial refrigeration” OR “refrigeration system” OR “refrigeration plant” OR “refrigeration”).

The search was conducted on 25 October 2025, and only studies published in English were considered. Various types of publications, including original research articles, systematic reviews, meta-analyses, and case studies, were reviewed for inclusion in this mini review to ensure comprehensive coverage of the topic.

Inclusion Criteria

The criteria for including research in this brief review were established to ensure that only the best studies, which fully address process safety issues, technological advances, and regulatory concerns related to ammonia-based refrigeration systems in the food sector, were chosen.

i. Studies on process safety risks and mitigation strategies for ammonia-based refrigeration systems in food processing and cold storage, including hazard identification, risk assessment models, and emergency response frameworks.
ii. Studies focus on technological interventions, such as automated leak detection, real-time monitoring sensors, and predictive maintenance systems that integrate IoT and AI to enhance ammonia safety management in the food sector.
iii. Studies analyzing strengths, limitations, and potential applications of ammonia-based refrigeration highlight its energy efficiency, zero ozone-depletion potential, and cost-effectiveness as key strengths, but also toxicity, corrosion risks, and regulatory challenges as primary limitations in industrial settings.
iv. Studies published in English emphasize occupational safety, environmental sustainability, and compliance with international safety standards.

Exclusion Criteria

The exclusion criteria were established to ensure that only reliable, relevant, and methodologically consistent papers were selected for this mini review by excluding sources that didn’t meet the scope or scientific rigor required.

i. Studies published in languages other than English were excluded to maintain consistency and ensure accurate interpretation of technical and safety-related terminology.
ii. Studies that discuss industrial refrigeration or food-sector safety without reference to ammonia-based refrigeration systems were excluded, as the review specifically focused on the role of ammonia as a refrigerant in enhancing process safety.
iii. Grey literature, including conference abstracts, unpublished reports, and non-peer-reviewed sources, was excluded to ensure the reliability, credibility, and scientific rigor of the findings presented in this mini review.

3. RESULTS AND DISCUSSION

A total of 53 papers were identified in the database search that can be used for this mini-review inquiry. However, only 32 publications met the criterion for empirical and review articles on enhancing process safety in ammonia-based refrigeration for the food industry. Figure 1 illustrates a fluctuating yet progressively rising pattern of document publications from 2003 to 2025. Early years show minimal output, followed by gradual growth, culminating in a significant peak in 2020. Although numbers decline afterward, the overall trend reflects sustained academic interest with moderate consistency in recent years.

The growth in publications shown in Figure 1 appears to be influenced by several global drivers. The increase after 2015 coincides with the adoption of Industry 4.0 technologies, including IoT-based monitoring, smart sensors, and predictive maintenance systems, which have expanded research on real-time ammonia leak detection and process safety optimization. The peak around 2019–2021 may reflect heightened academic attention following reported industrial ammonia incidents that triggered regulatory scrutiny and safety reassessment. Additionally, growing emphasis on ESG principles has strengthened research interest in balancing ammonia's environmental benefits with occupational safety and risk management requirements.

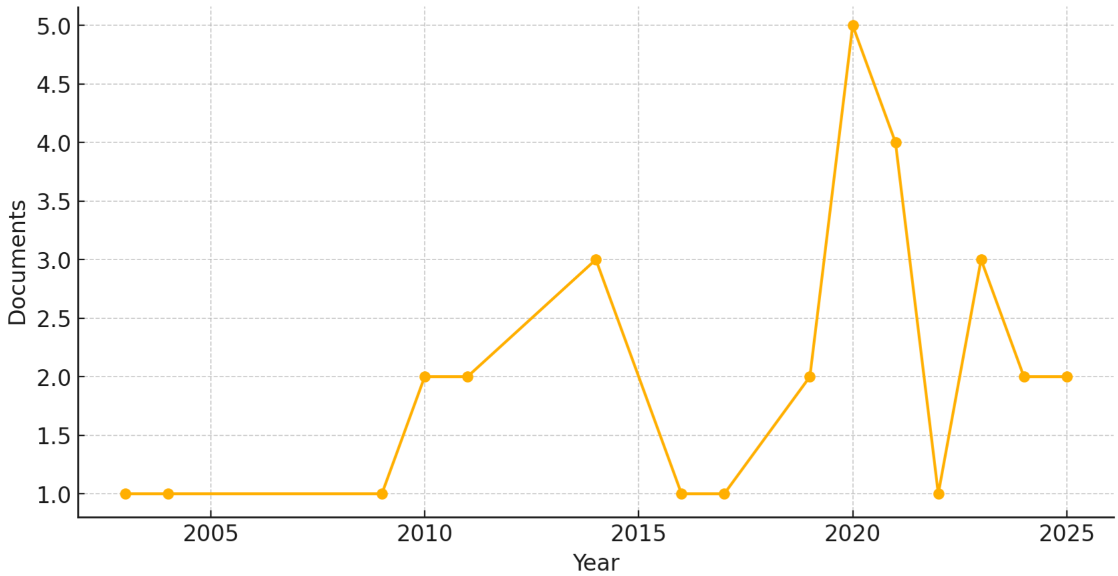

Figure 1: Research trends on process safety in ammonia-based refrigeration systems (2003–2025).

Safety enhancements in ammonia-based refrigeration are central to ensuring sustainable and reliable operations in the food manufacturing industry, where ammonia remains a highly efficient yet hazardous refrigerant. Due to its toxicity and flammability, recent developments have prioritized the implementation of advanced safety technologies, including automated leak detection systems, emergency ventilation controls, and integrated alarm networks. Studies have reported that adopting real-time monitoring and predictive maintenance, supported by IoT and AI analytics, significantly reduces the frequency and severity of ammonia-related incidents. Furthermore, risk-based inspection frameworks and adherence to safety standards, such as IIAR and ISO 5149, have strengthened preventive safety cultures across food processing plants.

Despite these advancements, debates persist over the cost-effectiveness of new safety technologies and the need for uniform global regulatory enforcement. Gaps remain in workforce training, safety audits, and data integration between equipment reliability and human performance. Currently, the literature underscores the importance of developing low-charge ammonia systems, hybrid refrigerant solutions, and digital safety dashboards. Future opportunities lie in combining smart technologies, enhanced operator training, and harmonizing global standards to achieve a balanced approach between operational efficiency, environmental responsibility, and superior process safety in the food refrigeration industry.

Figure 2 illustrates the thematic structure of contemporary research related to ammonia-based refrigeration in the food sector, revealing three primary areas of scholarly focus: operational efficiency, risk management, and safety enhancements. Studies on operational efficiency emphasize improving heat transfer and system performance by optimizing cold-storage operations, heat exchanger networks, cooling towers, and heat-integration strategies. In parallel, risk management research is increasingly focusing on advanced analytical frameworks, notably quantitative risk assessments and the Functional Resonance Analysis Method, to better identify, assess, and control ammonia-related hazards. Complementing these efforts, safety enhancement topics such as inspection procedures and accident prevention highlight ongoing initiatives to strengthen maintenance practices and minimize the likelihood of loss-of-containment events. Collectively, the figure emphasizes a balanced progression of innovations that simultaneously aim to enhance energy performance while reinforcing safety and regulatory compliance within ammonia-based refrigeration systems in the food industry.

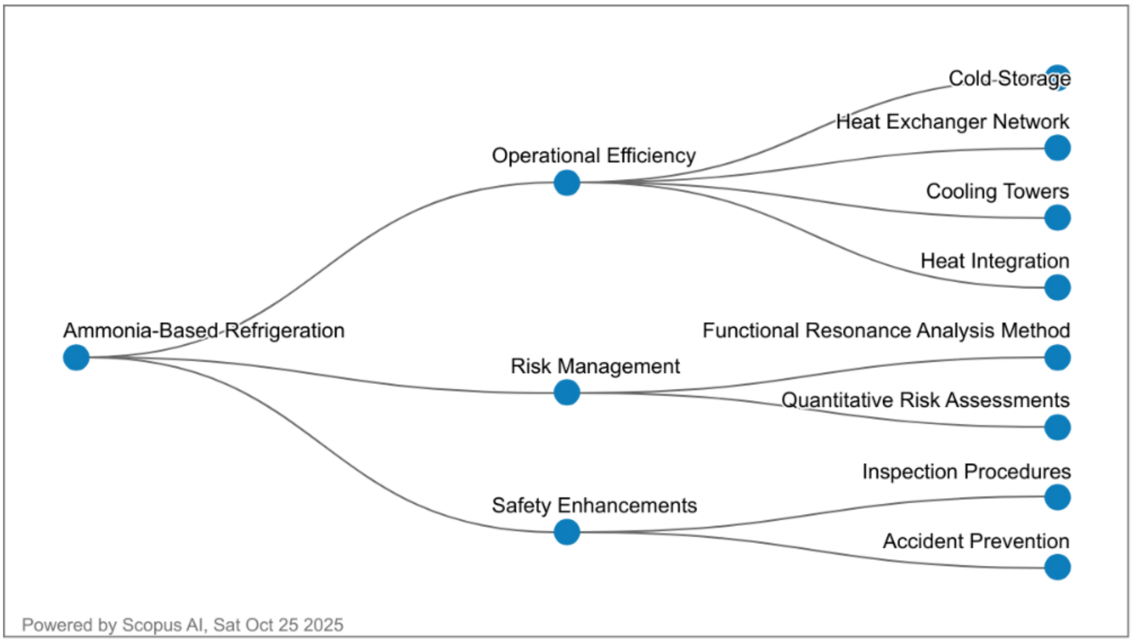

Figure 2: Concept map generated with Scopus AI for "Enhancing Process Safety in Ammonia-Based Refrigeration for the Food Industry".

3.1 Operational efficiency and energy-optimized process safety strategies

Ammonia-based refrigeration systems are crucial in the food industry, as they excel at cooling and are more cost-effective than other types of refrigerants. However, using them poses significant safety risks that must be continuously addressed in processes and risk management plans. To make operations more efficient while keeping people safe, you need to be fully aware of current safety practices and risk assessment tools.

Numerous studies have investigated the safety concerns associated with ammonia refrigeration systems. Khudhur et al. emphasize the importance of risk assessment and safety improvements in ammonia systems. They say that knowing more about possible dangers can make the workplace and the environment safer [4]. This evaluation provides a framework for assessing the operational safety of ammonia refrigeration, a vital component in the food industry due to its crucial role in food preservation and public health.

Additionally, the structural integrity of ammonia refrigeration parts is crucial, particularly the pressure piping used in cold storage facilities. Wang et al.'s research demonstrates that ammonia suction pipes can fail at high temperatures, highlighting the importance of strict construction and maintenance standards to prevent disasters [12]. The focus on strong materials and effective pressure management aligns with aspirations for operational efficiency, resulting in reduced downtime and increased productivity.

Al-Abdulally et al. also provide information on conducting a hazard study for refrigerated ammonia storage tanks. Their research highlights the need for systematic methodologies to assess tank failure probabilities and the potential consequences of leakage [13]. Industries can reduce hazards and improve operational efficiency by implementing effective safety measures, such as strengthening storage facilities and refining operating procedures.

The relevance of numerical modeling and computational methods in safety assessments is underscored in studies such as that by Zhang et al., which employs advanced computational fluid dynamics to model toxic gas release scenarios, contributing to improved risk assessment practices in ammonia facilities [14]. These methods enable operators to anticipate potential outcomes and adjust their safety measures accordingly, fostering a culture of proactive risk management.

The development of ammonia absorption refrigeration systems is also a sign that new technologies are being employed to enhance efficiency and minimize environmental impact. Lima et al.'s research demonstrates improvements in ammonia-absorbent systems, which enhance refrigeration performance while reducing the risks associated with direct ammonia use [15]. The information on thermodynamic properties and system advancements indicates that refrigeration processes in the food industry are becoming increasingly safe and efficient.

To summarize, making ammonia-based refrigeration safer in the food industry involves conducting thorough safety checks, adopting innovative technologies, and proactively managing risks. Combining information from different studies provides a complex approach to making things safer and more efficient, which is crucial for maintaining food safety.

3.2 Risk assessment and digital risk management frameworks

Risk management in ammonia refrigeration systems used in the food industry begins with comprehensive hazard evaluations to identify operational weaknesses that may lead to accidental releases. Food processing facilities such as dairy plants, seafood processing factories, poultry processing plants, and cold storage warehouses rely heavily on ammonia refrigeration systems to maintain the low temperatures required for product preservation and food safety. Any ammonia leakage may not only threaten worker safety but also disrupt production processes and compromise food quality.

Jaafar et al. discuss several safety issues associated with ammonia refrigeration systems and recommend employing structured risk assessment methods, such as fault tree analysis and risk analysis, to evaluate system vulnerabilities and identify potential accident scenarios [16]. In food industry facilities where refrigeration systems operate continuously, these systematic approaches help identify potential component failures, human errors during maintenance activities, and operational deviations that could trigger ammonia leaks.

Effective risk management requires assessment methods that keep pace with advances in safety technologies and data-driven management practices. Luo et al. introduced the PSD-RA method, which integrates key risk attributes and safety information needs using a "51X" indicator system and a four-tier evaluation model. This framework improves data-based safety decision-making and was validated in an operating ammonia refrigeration plant [17]. For food industry operators, such digital risk management approaches can support real-time monitoring of refrigeration equipment, enabling early detection of abnormal operating conditions that may lead to leaks.

Understanding possible accident scenarios and their consequences is also essential for managing risks in ammonia refrigeration systems. Rosa et al. evaluated ammonia leakage risks in an industrial refrigeration plant using PHAST modelling across several release scenarios [18]. Their findings showed that toxic dispersion could extend beyond the facility boundary and affect surrounding communities. In food processing plants where refrigeration systems often contain large ammonia inventories, consequence modelling plays a crucial role in emergency preparedness planning, evacuation strategy development, and the determination of appropriate safety distances.

Moreover, effective risk management in ammonia refrigeration plants should focus on identifying the most likely root causes of leakage incidents. Targeted preventive actions such as improved maintenance practices, component reliability monitoring, and operator training can significantly reduce the likelihood of ammonia releases. The framework proposed by Khudhur et al. demonstrates how object-oriented Bayesian networks can be used to analyze causal pathways and identify common failure causes within complex industrial systems [19]. This approach can help food industry operators prioritize critical safety improvements in refrigeration systems.

Finally, integrating digital technologies and continuous monitoring systems into the risk management framework is increasingly important for improving process safety. Dynamic safety analysis approaches discussed by Aneziris and Papazoglou enable early failure detection and strengthen system resilience [20]. In ammonia-based refrigeration systems used in food processing facilities, real-time monitoring of pressure, temperature, and gas-detection sensors can significantly reduce accident risk by enabling operators to respond immediately to abnormal conditions.

Overall, effective risk management in ammonia refrigeration systems within the food industry requires a combination of structured risk assessment methods, consequence modelling, digital monitoring technologies, and proactive safety management strategies to ensure operational reliability and worker protection.

3.3 Engineering controls and safety technology innovations

Enhancing process safety in ammonia-based refrigeration systems is particularly critical in the food industry, where refrigeration systems operate continuously to preserve food products and maintain hygienic storage conditions. Ammonia is widely used as a refrigerant due to its high thermodynamic efficiency and low environmental impact. However, its toxic and irritating properties pose significant safety hazards in the event of accidental leaks.

Exposure to high concentrations of ammonia can cause severe respiratory damage and chemical burns. A reported incident in a poultry processing facility demonstrated how accidental ammonia release can lead to serious health consequences for workers exposed to high concentrations of anhydrous ammonia [21]. Such incidents highlight the importance of implementing strong engineering controls and safety technologies in facilities that rely on ammonia refrigeration systems.

The design and maintenance of refrigeration system components play a crucial role in preventing ammonia leakage. Studies examining refrigerant flow characteristics, including mass flow rates through capillary tubes and system pressure behaviour, demonstrate that engineering design parameters significantly influence both system efficiency and operational safety [22]. In food processing plants, proper system design helps minimize pressure fluctuations and mechanical stresses that may lead to equipment failure.

In addition to proper system design, selecting appropriate construction materials and corrosion-resistant components is essential because ammonia can accelerate material degradation under certain operating conditions. Regular inspection and preventive maintenance programs are therefore necessary to ensure the long-term integrity of refrigeration equipment used in food processing facilities.

The application of inherently safer design (ISD) principles is another important strategy to reduce overall plant risk. ISD approaches focus on eliminating or minimizing hazards at the design stage rather than relying solely on protective measures [23-24]. In ammonia refrigeration systems, this may include reducing ammonia inventory, improving system containment, and optimizing equipment layout to minimize the consequences of leaks.

Technological innovations are also contributing to safer refrigeration practices. For example, alternative refrigeration technologies, such as solar absorption refrigeration systems using water–ammonia mixtures, are advancing to improve energy efficiency while maintaining safe operating conditions [25]. Although such systems are still emerging, they represent potential future solutions for sustainable refrigeration in the food sector.

In practical food industry operations, several engineering safety technologies are widely implemented to reduce the risk of ammonia release. These include ammonia gas detection systems, automatic ventilation systems in machine rooms, emergency shut-off valves, pressure relief devices, and secondary containment systems. Together, these engineering controls provide multiple layers of protection to safeguard workers, prevent major releases, and ensure uninterrupted refrigeration operations.

Furthermore, continuous safety monitoring and routine safety audits are essential to maintain safe system performance. Monitoring operational parameters such as pressure, temperature, and ammonia concentration allows early detection of abnormal conditions that may indicate potential leaks or equipment failures. By integrating engineering controls with proactive safety management practices, food processing facilities can significantly reduce the likelihood of ammonia-related accidents while maintaining stable refrigeration operations.

4. CONCLUSION

This mini review synthesized 32 peer-reviewed studies published between 2003 and 2025, with research activity remaining limited prior to 2015 before increasing significantly and peaking in 2020 (n = 5). Methodologically, 75% of the studies employed quantitative risk assessment (QRA) approaches, while 50% utilized HAZOP for structured hazard identification. However, only 40% of the reviewed studies examined digital monitoring, smart sensors, or predictive maintenance technologies aligned with Industry 4.0 applications, indicating that technological integration in ammonia safety management remains comparatively underexplored.

Overall, the findings confirm that ammonia-based refrigeration systems continue to offer operational and environmental advantages, yet safety management practices remain uneven and highly dependent on regulatory maturity and organizational capacity. Despite the dominance of QRA-based approaches, gaps persist in field validation, long-term performance evaluation, and cost–benefit justification of advanced mitigation systems. Future research should prioritize integrating quantitative risk modelling with real-time digital safety technologies and harmonized regulatory frameworks to strengthen both sustainability and process safety resilience in the food industry.

Regarding safety enhancements, emerging trends such as smart sensors, automated leak detection, and AI-assisted predictive maintenance offer promising avenues to reduce the likelihood and severity of accidents. Nonetheless, unresolved gaps persist in validating these technologies under real-world conditions, optimizing human–machine collaboration, and balancing automation and operator oversight. Moreover, data scarcity on long-term safety performance and the cost–benefit relationship of advanced mitigation systems constrain evidence-based policy and investment decisions.

Looking ahead, future research should focus on integrating energy efficiency metrics with quantitative risk modelling to develop comprehensive decision frameworks that align safety, sustainability, and economic feasibility. Cross-disciplinary studies that combine engineering, data analytics, and human factors are necessary to refine predictive maintenance tools and assess their effectiveness in diverse food processing contexts. Practically, fostering stronger industry–regulator collaboration, developing standardized training programs, and encouraging the adoption of digital safety technologies will be vital to achieving a resilient, efficient, and inherently safer ammonia refrigeration landscape.

In conclusion, enhancing process safety in ammonia-based refrigeration requires a balanced approach that integrates technological innovation, human reliability, and regulatory support to ensure the continued safety, sustainability, and competitiveness of the global food industry.

ACKNOWLEDGEMENTS

This work was supported by the Universiti Kebangsaan Malaysia through a Research Project with grant number DIP2.0 (DIP-2023-010).

REFERENCES

[1] Luo, C., Zhao, Y., & Xu, K. Study on the Regularity of Ammonia-Related Refrigeration Accidents in China from 2010 to 2020. International Journal of Environmental Research and Public Health, vol 19, issue 14 (2022).

[2] Xu, Y., Wang, Y., Lei, Z., Wang, C., Meng, X., & Cheng, P. MXene-Based Gas Sensors for NH3 Detection: Recent Developments and Applications. Micromachines, vol 16, issue 7 (2025) p. 820.

[3] Kypraiou, C., & Varzakas, T. Evolution and Evaluation of Ultra-Low Temperature Freezers: A Comprehensive Literature Review. Foods, vol 14, issue 13 (2025) p. 2298.

[4] Khudhur, D.A., Tuan Abdullah, T.A., & Norazahar, N. A Review of Safety Issues and Risk Assessment of Industrial Ammonia Refrigeration System. ACS Chemical Health and Safety, vol 29, issue 5 (2022) pp. 394–404.

[5] Zhao, Y., Yang, Z., Hou, Z., Guo, C., Zhang, S., & He, H. Dynamic modeling and leak detection of ammonia leakage in food cold storage system. Journal of Food Process Engineering, vol 46, issue 12 (2023).

[6] Soujoudi, R., & Manteufel, R. Thermodynamic, Economic and Environmental Analyses of Ammonia-Based Mixed Refrigerant for Liquefied Natural Gas Pre-Cooling Cycle. Processes, vol 9, issue 8 (2021) p. 1298.

[7] Costella, M.F., Pelegrini, G.A., Bortolosso, H., Vicari, P., & Dalcanton, F. Exploring the relationships between safety and maintenance in the cold generation process: insights from the functional resonance analysis method. International Journal of Occupational Safety and Ergonomics, vol 29, issue 1 (2023) pp. 216–223.

[8] Abed, A.M., Alghoul, M.A., Sirawn, R., Al-Shamani, A.N., & Sopian, K. Performance enhancement of ejector–absorption cooling cycle by re-arrangement of solution streamlines and adding RHE. Applied Thermal Engineering, vol 77, (2015) pp. 65–75.
[9] Nair, S., Mazurek-Kusiak, A., Trafiałek, J., & Kolanowski, W. Assessing Food Safety Compliance in a Small-Scale Indian Food Manufacturer: Before and After Certification of the Food Safety Management System and Foreign Supplier Verification Program. Applied Sciences, vol 13, issue 22 (2023) p. 12190.
[10] Stoyanova, A., Marinova, V., Stoilov, D., & Kirechev, D. Food Safety Management System (FSMS) Model With Application of the PDCA Cycle and Risk Assessment as Requirements of the ISO 22000:2018 Standard. Standards, vol 2, issue 3 (2022) pp. 329–351.
[11] Lee, J.C., Darabă, A., Voidarou, C., Rozos, G., El Enshasy, H.A., & Varzakas, T. Implementation of Food Safety Management Systems Along With Other Management Tools (HAZOP, FMEA, Ishikawa, Pareto). The Case Study of Listeria Monocytogenes and Correlation With Microbiological Criteria. Foods, vol 10, issue 9 (2021) p. 2169.
[12] Wang, W., Chen, J., Li, J., Hu, L., & Jing, W. The failure mechanism of ammonia suction pipe bursting under fire environment. Journal of Physics: Conference Series, vol 2825, issue 1 (2024) p. 012026.
[13] Al-Abdulally, F., Al-Shuwaib, S., & Gupta, B.L. Hazard Analysis and Safety Considerations in Refrigerated Ammonia Storage Tanks.
[14] Zhang, B., Liu, Y., & Qiao, S. A Quantitative Individual Risk Assessment Method in Process Facilities with Toxic Gas Release Hazards: A Combined Scenario Set and CFD Approach. Process Safety Progress, vol 38, issue 1 (2019) pp. 52–60.
[15] Lima, A.A.S., et al. Absorption refrigeration systems based on ammonia as refrigerant using different absorbents: Review and applications. Energies, vol 14, issue 1 (2021).
[16] Jaafar, M.N., Rosli, M.I., Nordin, D., & Buhari, J. Systematic literature review on the risk assessment of ammonia refrigeration systems in the food industry. Journal of Loss Prevention in the Process Industries, vol 96, (2025).
[17] Luo, C., Zhao, Y., & Xu, K. A risk assessment method considering risk attributes and work safety informational needs and its application. Chinese Journal of Chemical Engineering, vol 68, (2024) pp. 253–262.
[18] Rosa, A.C., et al. Quantitative risk analysis applied to refrigeration's industry using computational modeling. Results in Engineering, vol 9, (2021).
[19] da Silva, E.P., Filho, N.R.A., Pereira, J., & Formiga, K.T.M. Temporal variation and risk assessment of heavy metals and nutrients from water and sediment in a stormwater pond, Brazil. Water Supply, vol 23, issue 1 (2023) pp. 206–221.
[20] Aneziris, O.N., & Papazoglou, I.A. Fast Markovian method for dynamic safety analysis of process plants. Journal of Loss Prevention in the Process Industries, vol 17, issue 1 (2004) pp. 1–8.
[21] Ortiz-Pujols, S., et al. Management and Sequelae of a 41-Year-Old Jehovah's Witness with Severe Anhydrous Ammonia Inhalation Injury. Journal of Burn Care and Research, vol 35, issue 3 (2014).
[22] Nouri-Borujerdi, A., & Javidmand, P. Critical Mass Flow Rate Through Capillary Tubes. Proceedings of the ASME 2010 3rd Joint US-European Fluids Engineering Summer Meeting and 8th International Conference on Nanochannels, Microchannels, and Minichannels (2010).
[23] Jain, V., Singhal, A., Sachdeva, G., & Kachhwaha, S.S. Advanced exergy analysis and risk estimation of novel NH3-H2O and H2O-LiBr integrated vapor absorption refrigeration system. Energy Conversion and Management, vol 224, (2020).
[24] Eini, S., Shahhosseini, H., Delgarm, N., Lee, M., & Bahadori, A. Multi-objective optimization of a cascade refrigeration system: Exergetic, economic, environmental, and inherent safety analysis. Applied Thermal Engineering, vol 107, (2016) pp. 804–817.
[25] Dardouch, J., Charia, M., & Bernatchou, A. Numerical study of a Solar Absorption Refrigeration Machine. E3S Web of Conferences (2020).

Conflict of interest statement: The authors declare no conflict of interest.

Author contributions statement: Conceptualization, M.N. Jaafar & M.I. Rosli; Methodology, M.N. Jaafar & H.F. Hanafi; Validation, M.N. Jaafar & M.I. Rosli; Data Curation, M.N. Jaafar; Writing – Original Draft Preparation, M.N. Jaafar; Writing – Review & Editing, M.I. Rosli, D. Nordin & H.F. Hanafi; Supervision, M.I. Rosli & D. Nordin.

Declaration of Generative AI Use: During the preparation of this manuscript, the author(s) used Scopus AI (Concept Map tool) to generate a conceptual visualization that assisted in organizing and synthesizing the reviewed literature. The output generated by this tool was carefully reviewed, validated against the original sources, and refined where necessary. The author(s) assume full responsibility for the accuracy, integrity, and final content of the manuscript.