Safety Analysis of the Use of Hydrocarbon Refrigerants in Refrigeration Systems Based on Safety Standards and Technician Competence

Khairul[1*], Ulpen Hiermy[2], I Putu Hikariantara[3], Istianto Budhi Rahardja[4]
[1,2,3] Teknik Mesin, Sekolah Tinggi Teknologi Bina Tunggal, Kota Bekasi, Kode Pos 171312
[4] Teknik Mesin, Sekolah Vokasi, Institut Teknologi Perusahaan Listrik Negara, Menara PLN, Jl. Lingkar Luar Barat, Duri Kosambi, Cengkareng, Jakarta Barat, 11750

**Email Author: khairul3273@gmail.com*

ABSTRAK

Penggunaan refrigeran hidrokarbon pada sistem pendingin terus meningkat sebagai alternatif pengganti refrigeran sintetis karena memiliki nilai *Ozone Depletion Potential* (ODP) mendekati nol, *Global Warming Potential* (GWP) rendah, serta efisiensi energi yang baik. Namun, sifat mudah terbakar refrigeran hidrokarbon menimbulkan risiko keselamatan yang memerlukan penerapan standar keselamatan dan kompetensi teknisi secara konsisten. Penelitian ini bertujuan menganalisis keselamatan penggunaan refrigeran hidrokarbon berdasarkan penerapan standar keselamatan dan kompetensi teknisi melalui pendekatan *Systematic Literature Review* (SLR). Metode penelitian mengacu pada pedoman PRISMA 2020 dengan menganalisis literatur ilmiah, standar internasional, dan dokumen teknis yang dipublikasikan pada periode 2021–2025. Hasil sintesis menunjukkan bahwa tingkat keselamatan dipengaruhi oleh tiga faktor utama, yaitu karakteristik refrigeran hidrokarbon, implementasi standar keselamatan, dan kompetensi teknisi. Standar seperti ISO 5149, IEC 60335-2-40, EN 378, dan ISO 817 menyediakan kerangka pengendalian risiko, namun efektivitasnya sangat bergantung pada kemampuan teknisi dalam menerapkan prosedur instalasi, pemeliharaan, deteksi kebocoran, dan penanganan refrigeran secara benar. Penelitian ini mengusulkan model konseptual yang mengintegrasikan standar keselamatan dan kompetensi teknisi sebagai faktor utama dalam menurunkan risiko kecelakaan pada sistem pendingin. Hasil penelitian diharapkan menjadi referensi bagi industri, institusi pendidikan, lembaga sertifikasi profesi, dan regulator dalam meningkatkan keselamatan penggunaan refrigeran hidrokarbon.

Kata kunci: refrigeran hidrokarbon; keselamatan kerja; sistem pendingin; standar keselamatan; kompetensi teknisi; *Systematic Literature Review*.

ABSTRACT

The application of hydrocarbon refrigerants in refrigeration systems has increased significantly as an environmentally friendly alternative to synthetic refrigerants due to their near-zero Ozone Depletion Potential *(ODP), low* Global Warming Potential *(GWP), and high energy efficiency. However, their flammable characteristics introduce safety risks that require strict implementation of safety standards and adequate technician competency. This study aims to analyze the safety of hydrocarbon refrigerant applications based on safety standards and technician competency using a* Systematic Literature Review *(SLR) approach. The review followed the PRISMA 2020 guideline and examined scientific publications, international standards, and technical documents published between 2021 and 2025. The synthesis indicates that safety performance is primarily determined by three interrelated factors: hydrocarbon refrigerant characteristics, implementation of safety standards, and technician competency. International standards, including ISO 5149, IEC 60335-2-40, EN 378, and ISO 817, provide comprehensive risk-control frameworks; however, their effectiveness depends on technicians' ability to perform installation, maintenance, leak detection, and refrigerant handling in accordance with established procedures. This study proposes a conceptual model integrating safety standards and technician competency as the primary determinants for reducing accident risks in refrigeration systems. The findings provide practical references for industry, higher education institutions, professional certification bodies, and policymakers to strengthen the safe application of hydrocarbon refrigerants.*

Keywords: *hydrocarbon refrigerant; occupational safety; refrigeration system; safety standards; technician competency; Systematic Literature Review*.

1. INTRODUCTION

The development of refrigeration system technology in recent decades shows a significant shift towards the use of more environmentally friendly refrigerants [1,2]. International policies through *the Montreal Protocol* and *the Kigali Amendment* encourage the reduction of the use of synthetic refrigerants that have high *Ozone Depletion Potential* (ODP) and *Global Warming Potential* (GWP) values[1], [3]. Alternatively, hydrocarbon refrigerants such as propane (R290), isobutane (R600a), and propylene (R1270) are increasingly being applied because they have near-zero ODP, very low GWP, and thermodynamic characteristics that can improve the energy efficiency of refrigeration systems [4],[6]. This development makes hydrocarbon refrigerants one of the important solutions in supporting sustainable refrigeration technology.

In addition to their benefits to the environment and energy efficiency, hydrocarbon refrigerants have flammable characteristics that pose new challenges in terms of occupational safety [7,8]. Based on the ISO 817 classification, hydrocarbon refrigerants belong to the A3 group with a high flammability level so they require stricter risk control than non-flammable refrigerants [9]. The risk of fire and explosion can occur when there is a leak of refrigerant mixed with air at a certain concentration and meets the ignition source [10,11]. Therefore, the successful implementation of hydrocarbon refrigerants is determined not only by their technological advantages, but also by the effectiveness of the safety system implemented during the installation, operation, maintenance, and repair of the refrigeration system [7], [12].

Studies have shown that most incidents in hydrocarbon refrigeration systems are not solely caused by the characteristics of the refrigerant, but are influenced by human *factors*, non-conformities in work procedures, the use of equipment that does not meet safety requirements, and low compliance with applicable standards [13], [15]. Errors in the *recovery*, *charging*, leak testing, and welding work on systems that still contain refrigerant are the causes that are often reported in various studies. This condition shows that improving safety is not enough to be done through improving the system design, but also requires increasing the competence of technicians as the main implementers of work in the field [15], 17].

To control these risks, various international organizations have developed safety standards that govern system design, maximum limits for refrigerant charging, space ventilation, leak detection, installation procedures, and maintenance requirements [18], [21]. Standards such as ISO 5149, IEC 60335-2-40, EN 378, and ISO 817 have become a reference in the use of hydrocarbon refrigerants in various sectors [9], [12], [18], [19]. In Indonesia, the implementation of these standards is strengthened through the Indonesian National Standard (SNI), the Indonesian National Work Competency Standard (SKKNI), and the implementation of technician competency certification [22.23]. However, the implementation of safety standards in the field still faces various challenges, especially in the installation and service services sector that involves technicians with varying levels of competence [24,25].

Studies on hydrocarbon refrigerants have been dominated by research focusing on thermodynamic performance, energy efficiency, and environmental impact [26], [28]. Other studies have addressed fire risk analysis as well as evaluation of safety standards separately [29, 30]. However, studies that integrate the safety aspects of the use of hydrocarbon refrigerants with the application of safety standards and technician competencies through the *Systematic Literature Review approach* are still relatively limited, especially in the context of implementation in refrigeration systems [31,32]. These limitations have led to the unavailability of a scientific synthesis that is able to comprehensively explain the relationship between factors as the basis for the development of occupational safety policies.

Based on these conditions, this study offers a synthesis that connects three main aspects, namely safety standards, technician competence, and safety risks of using hydrocarbon refrigerants. Through the *Systematic Literature Review approach* that refers to the PRISMA 2020 guidelines [29], This study not only summarizes the results of previous research, but also develops a conceptual model that explains the relationship between these three aspects in reducing the potential for work accidents in the cooling system. This approach is expected to make a more comprehensive scientific contribution than previous research which generally only reviews one aspect separately.

This study aims to analyze the safety of the use of hydrocarbon refrigerants in refrigeration systems based on the application of safety standards and

technician competencies through a synthesis of scientific literature published during the period 2021–2025. The results of the research are expected to be a reference for industry, educational institutions, professional certification bodies, and regulators in formulating strategies to improve occupational safety, develop technician competencies, and implement safety standards in the use of hydrocarbon refrigerants in Indonesia.

2. HIDROCARBON REFRIGERANTS

2.1 Hydrocarbon Refrigerants and Safety Aspects

Hydrocarbon (HC) refrigerants, such as propane (R290), isobutane (R600a), and propylene (R1270), are a group of natural refrigerants that are widely used as alternatives to synthetic refrigerants because they have a *near-zero Ozone Depletion Potential* (ODP) value and a very low *Global Warming Potential* (GWP) [4-6]. In addition to providing benefits from environmental aspects, hydrocarbon refrigerants also have thermodynamic characteristics that are able to increase the energy efficiency of the refrigeration system [4,5]. Nevertheless, hydrocarbon refrigerants are classified as A3 refrigerants according to ISO 817 because they have a high flammability rate [9]. Therefore, its use requires risk control through safe system design, limiting the amount of refrigerants, adequate ventilation, leak detection, and work procedures that comply with safety standards [12], [18].

2.2 Safety Standards and Technician Competence

The risk control of the use of hydrocarbon refrigerants refers to various international standards, including ISO 5149, IEC 60335-2-40, EN 378, and ISO 817 [9], 12], [18,19]. The standard regulates safety requirements starting from the system design stage, installation, operation, maintenance, to emergency handling [18], [20]. Although the standard has provided comprehensive technical guidelines, the effectiveness of its implementation depends heavily on the competence of the technician [15], [23]. These competencies include knowledge of refrigerant characteristics, the ability to identify hazards, use of appropriate equipment, *recovery* and *charging procedures*, leak testing, and the implementation of occupational safety procedures [15], [21]. In the Indonesian context, the development of technician competencies is supported through the Indonesian National Work Competency Standards (SKKNI) and professional certifications that aim to ensure that work is carried out in accordance with safety standards and industry needs [23].

2.3 Previous Research and Conceptual Framework

Research on hydrocarbon refrigerants in the last five years has generally focused on improving energy efficiency, thermodynamic performance, and reducing environmental impact. Other studies examine the flammability characteristics of hydrocarbon refrigerants, risk analysis, and the implementation of safety standards in various refrigeration system applications. However, most of these studies still address technical or safety aspects separately. Studies that integrate the relationship between safety standards, technician competence, and safety risk levels through *the Systematic Literature Review approach* are still relatively limited.

Based on these conditions, this study uses a conceptual framework that places safety standards as the basis for risk control, technician competence as an implementation factor, and refrigeration system safety as the expected output. The relationship between these three aspects is the basis for the process of synthesizing literature and analyzing research results to explain how the application of safety standards and improving the competence of technicians contribute to reducing the risk of accidents in the use of hydrocarbon refrigerants.

3. RESEARCH METHODOLOGY

This study uses **the Systematic Literature Review (SLR)** method to identify, evaluate, and synthesize research results regarding the safety of the use of hydrocarbon refrigerants in refrigeration systems based on the application of safety standards and technician competence [29]. The study process is carried out systematically referring to the guidelines of **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020**, so that the stages of identification, selection, and synthesis of literature can be carried out transparently and can be replicated [29].

3.1 Research Questions

Research Questions are compiled as the basis for the search and synthesis process of literature as shown in Table 1.

Table 1. Research Questions

Code	Research Question
RQ1	What are the factors that affect the safety of using hydrocarbon refrigerants in refrigeration systems?
RQ2	How does the implementation of safety standards contribute to reducing the risk of work accidents?
RQ3	How does the competence of technicians affect the safety implementation of the use of hydrocarbon refrigerants?

3.2 Literature Search Strategy

The literature search was conducted on international scientific databases that are widely used in the fields of mechanical engineering, refrigeration, and occupational safety, namely Scopus, ScienceDirect, SpringerLink, IEEE Xplore, and Google Scholar. Selected articles are limited to publications in **2021–2025** to reflect the latest research developments.

Table 2. Database and Search Strategy

Basis Data	Kata Kunci Utama
Scopus	Hydrocarbon Refrigerant, R290, Refrigeration Safety
ScienceDirect	Hydrocarbon Refrigerant AND Safety
SpringerLink	Refrigeration System AND Technician Competency
IEEE Xplore	Refrigeration Safety Standard
Google Scholar	Hydrocarbon Refrigerant Safety

Keyword combinations use Boolean operators (**AND** and **OR**) to improve the relevance of search results, focusing on hydrocarbon refrigerants, occupational safety, safety standards, and technician competence [29].

3.3 Literature Selection Criteria

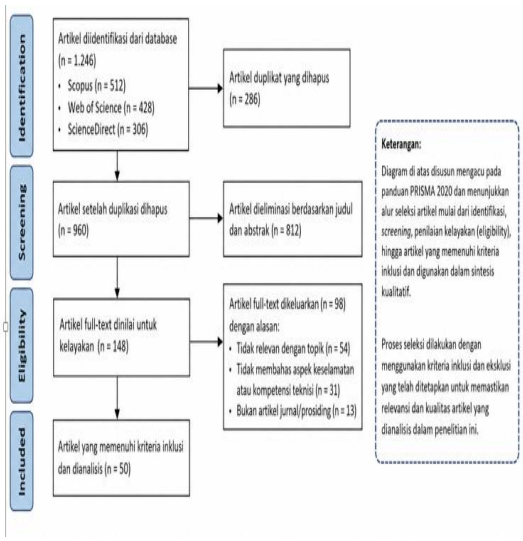
Articles were selected based on inclusion and exclusion criteria to ensure fit with the research objectives.

Table 3. Inclusion and Exclusion Criteria

Criteria	Inclusions	Exclusion
Year of publication	2021–2025	Before 2021*
Document type	Journal articles, proceedings, international standards	Editorial, opinion, abstract only
Language	Indonesia and English	Other than Indonesia and English
Topics	HC refrigerant, safety, standards, technician competence	Irrelevant to the topic

*International standards such as ISO 5149, ISO 817, IEC 60335-2-40, and EN 378 are still used even if they were published before 2021 because they are still the applicable references.

Figure 1. PRISMA Diagram



3.4 Data Selection and Analysis

The article selection process follows the PRISMA 2020 stages which include **identification**, screening, **eligibility**, and **included**. In the identification stage, all articles obtained from various databases are collected, then duplicate articles are deleted. The next stage is screening based on titles and abstracts, followed by *full text assessment* to ensure suitability for the research objectives. The entire selection process is planned to be presented in the form of **a PRISMA 2020 flowchart** [29] in the research results section.

Articles that met the criteria were then extracted based on several aspects, including the year of publication, the country of origin of the research, the type of hydrocarbon refrigerant, the object of the research, the safety standards used, the aspects of technician competence, the research method, and the main findings. Furthermore, the data was analyzed using **thematic synthesis** by grouping the research results into four main themes, namely: (1) the risk characteristics of hydrocarbon refrigerants, (2) the implementation of safety standards, (3) the competence of technicians, and (4) risk mitigation strategies. The results of the synthesis are presented in the form of tables, comparison matrices, and conceptual models to facilitate interpretation and support comprehensive discussions.

4. RESULTS AND DISCUSSION

4.1 Characteristics of the Literature Analyzed

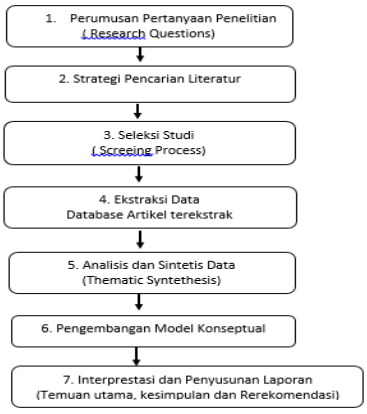
Based on the selection process using the PRISMA 2020 guidelines, articles that meet the inclusion criteria are then analyzed based on the characteristics of the publication, the country of origin of the research, the type of hydrocarbon refrigerant, the focus of the research, the method used, and the safety standards that are references. The literature characterization aims to provide an overview of the development of hydrocarbon refrigerant safety research as well as show the research space that is still open.

Table 4. Characteristics of Analyzed Articles

Aspects	Category
Publication period	2021–2025
Document type	Journal articles, proceedings, international standards [26]
Field of study	Refrigeration, HVAC, occupational safety, energy
Types of refrigerants	R290, R600a, R1270
Research methods	Experiments, simulations, case studies, reviews
Reference standards	ISO 5149, IEC 60335-2-40, EN 378, ISO 817

This table shows that hydrocarbon refrigerant safety research is multidisciplinary and focuses not only on aspects of system performance, but also includes operational safety, technician competence, and compliance with international standards.

Figure2. Flowchart Research Methodology



4.2 Hydrocarbon Refrigerant Research Trends

During the 2021–2025 period, there will be an increase in attention to hydrocarbon refrigerants along with the transition to low-GWP refrigerants. In addition to energy efficiency aspects, research has begun to discuss the safety of the use of flammable refrigerants, risk analysis, and improving the competence of technicians as part of risk mitigation strategies. The latest study also emphasizes the importance of refrigerant operation, maintenance, and *recovery* procedures carried out by competent personnel in accordance with ISO 5149 requirements.

Table 5. Research Theme for 2021–2025

Research Theme	Study Focus
Energy efficiency	COP, energy consumption
Natural refrigerants	R290, R600a, R1270
Safety	Fire and explosion risk
Standard	ISO 5149, IEC 60335-2-40, EN 378
Competencies	Technician training and certification
Risk management	Hazard identification and risk assessment

The analysis shows a shift in research focus from thermodynamic performance evaluation to the integration of safety and sustainability aspects [4,5], [8]. This shows that the success of hydrocarbon refrigerant implementation is no longer measured only by energy efficiency, but also by the ability of systems and personnel to control operational risks.

4.3 Safety Standard Analysis

A synthesis of the literature shows that international standards have complementary roles in controlling the risks of using hydrocarbon refrigerants. ISO 5149 emphasizes aspects of the design, installation, operation, maintenance, and recovery of refrigerants by competent personnel. IEC 60335-2-40 regulates refrigerant filling limits and equipment safety requirements, while EN 378 focuses on refrigeration system safety and risk analysis. ISO 817 is used as a reference for refrigerant classification based on toxicity and flammability level. The latest requirements also emphasize the importance of *hazard analysis*, leak testing, vacuum procedures, and documentation before the system is re-operational.

Table 6. Comparison of Safety Standards

Standard	Scope	Contribution to Safety
ISO 5149	Refrigeration system	Design, operation, maintenance, *recovery*
IEC 60335-2-40	Air conditioning and heat pump equipment	Refrigerant recharge limit
EN 378	Install the system.	Ventilation, leak detection, risk analysis
ISO 817	Refrigerant classification	Determination of class A3 and flammability characteristics

Based on the synthesis results, there is no single standard that is able to control all aspects of risk independently [10], [15], [18]. Therefore, the implementation of safety requires the application of standards in an integrated manner according to the characteristics of the cooling system.

4.4 Safety Risk Factors

A synthesis of the literature shows that the risk of using hydrocarbon refrigerants is influenced by the interaction between technical factors, human factors, and working environmental conditions. The majority of publications conclude that incidents are more often triggered by failure to implement procedures than by the characteristics of the refrigerant itself. The ISO 5149 standard also requires maintenance, repair, *recovery*, welding, and replenishment work to be carried out by competent personnel and preceded by hazard analysis and leak testing.

Table 7. Synthesis of Risk Factors and Mitigation Strategies

Risk factor	Impact	Mitigation Strategies
Refrigerant leaks	Fire	Leak test, ventilation

Ignition source	Explosion	Elimination ignition source
Welding	Refrigerant ignition	Recovery and purging nitrogen
Overcharging	Excessive pressure	Charging to standard
Human error	Work accidents	Training and certification

The analysis shows that most of the risks can be reduced through the correct implementation of work procedures, the use of equipment according to specifications, and supervision of technician compliance.

4.5 Technician Competencies and Standard Implementation

Technician competence is a connecting factor between safety standards and implementation in the field. Technicians who understand the characteristics of hydrocarbon refrigerants are able to identify hazards, choose the right work methods, carry out *recovery*, vacuum, leak testing, and refrigerant filling according to procedures. On the other hand, low competence increases the likelihood of *unsafe acts* that have the potential to trigger accidents.

Table 8. The Relationship of Technician Competence to Safety

Competencies	**Influence on Safety**
Hazard identification	Very high
Leak detection	Very high
Recovery refrigeran	Very high
Vacuum system	Height
Charging refrigeran	Very high
Job documentation	Medium

These findings show that investment in the development of technician competencies has as important a contribution as investment in refrigeration system technology.

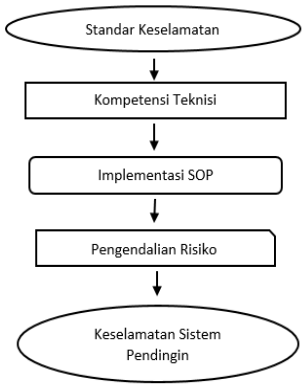
4.6 Research Synthesis and Conceptual Models

Based on the overall results of the synthesis, this study proposes a conceptual model that explains that the safety of the use of hydrocarbon refrigerants is the result of the interaction between three main components, namely safety standards, technician competence, and implementation of work procedures. The standard serves as a regulatory framework, while the competence of technicians determines the quality of implementation in the field. The interaction of the two components results in a reduction in the risk of leaks, fires, and work accidents.

Table 9. Synthesis Model of Research Results

Components	**Role**	**Impact**
Safety standards	Technical guidelines	Risk control
Technician competence	Implementation	Procedural compliance
SOP	Standardization of work	Consistency of operation
Risk management	Monitoring	Accident prevention
System security	Output	Safe operation

Figure 3. Conceptual Model



This conceptual model is a major contribution of the research because it shows that safety improvement depends not only on the characteristics of the refrigerant or system design, but also on the competence of personnel applying the standards in the field. This approach is in line with the development of the ISO 5149 standard which emphasizes that the operation, maintenance, repair, *recovery*, and testing of the system must be carried out by competent personnel through hazard analysis, leak testing, vacuum procedures, and adequate documentation.

5. CONCLUSION

This study analyzes the safety of the use of hydrocarbon refrigerants in refrigeration systems based on the application of safety standards and technician competencies through the *Systematic Literature Review* (SLR) approach. The results of the literature synthesis show that hydrocarbon refrigerants, such as R290, R600a, and R1270, are alternative refrigerants that have good thermodynamic performance, high energy efficiency, and *a near-zero Ozone Depletion Potential* (ODP) value and a very low *Global Warming Potential* (GWP). However, the flammability characteristics of hydrocarbon refrigerants demand the implementation of a stricter safety system than conventional refrigerants. The results of the study show that the level of safety of hydrocarbon refrigerant use is influenced by three main factors, namely the application of safety standards, technician competence, and compliance with operational procedures. International standards such as ISO 5149, IEC 60335-2-40, EN 378, and ISO 817 provide comprehensive guidelines on system design, refrigerant charge limits, installation, operation, maintenance, leak detection, and handling of refrigerants. However, the effectiveness of the implementation of these standards is highly dependent on the ability of technicians to identify potential hazards, use appropriate equipment, and carry out work procedures correctly and consistently. Through the synthesis of various research results, this study proposes a conceptual model that places safety standards and technician competence as two main factors that support each other in reducing the risk of work accidents in hydrocarbon refrigerant-based refrigeration systems [15]. Thus, improving safety depends not only on technology and system design, but also on the development of human resources through education, training, and competency certification. The findings of this study are expected to be a reference for industry, educational institutions, professional certification bodies, and regulators in improving the safety implementation of the sustainable use of hydrocarbon refrigerants.

References

[1] UNEP, *Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer*, 2022.

[2] IEA, *The Future of Cooling*, 2023.

[3] UNEP, *Global Cooling Watch Report*, 2023.

[4] Mota-Babiloni, J. Navarro-Esbrí, Á. Barragán-Cervera, *et al.*, "Judul artikel," *Applied Sciences*, vol. xx, no. xx, pp. xx–xx, 2021.

[5] Ghanbarpour et al., *International Journal of Refrigeration*, 2022.

[6] Ibrahim et al., *Cleaner Engineering and Technology*, 2024

[7] A. Mota-Babiloni, J. Navarro-Esbrí, Á. Barragán-Cervera, et al., *Natural Refrigerants for Sustainable Refrigeration Systems: Current Status and Future Perspectives*, Applied Sciences, vol. 11, no. 13, 2021

[8] O. A. Ibrahim, et al., *Hydrocarbon Refrigerants as Low-GWP Alternatives in Refrigeration Systems: A Review*, Cleaner Engineering and Technology, 2024.

[9] ISO 817:2014+A1:2017, *Refrigerants — Designation and Safety Classification*.

[10] J. G. Calm, *Safety Considerations for Flammable Refrigerants in Refrigeration Systems*, International Journal of Refrigeration, 2022.

[11] Y. Li, X. Wang, and H. Chen, *Safety Assessment of R290 Refrigeration Systems under Leakage Conditions*, Applied Thermal Engineering, 2022.

[12] IEC 60335-2-40:2022, *Household and Similar Electrical Appliances – Safety – Part 2-40*.

[13] A. Palm, *Human Factors in Refrigeration Safety: A Systematic Review*, International Journal of Refrigeration, 2023.

[14] O. A. Ibrahim, et al., *Safety Management of Hydrocarbon Refrigerants: Lessons from Recent Studies*, Cleaner Engineering and Technology, 2024.

[15] International Institute of Refrigeration (IIR), *Guidelines for Safe Handling of Flammable Refrigerants*, 2023.

[16] X. Zhang, H. Liu, and Y. Chen, *Risk Analysis of Refrigerant Leakage and Ignition in Hydrocarbon Refrigeration Systems*, Applied Thermal Engineering, 2022.

[17] International Labour Organization (ILO), *Safety and Health at Work: Guidelines for Hazardous Refrigerants*, 2022.

[18] ISO 5149-1:2014, *Refrigerating Systems and Heat Pumps—Safety and Environmental Requirements.*

[19] EN 378:2016+A1:2020, *Refrigerating Systems and Heat Pumps—Safety and Environmental Requirements.*

[20] IEC 60335-2-40:2022, *Household and Similar Electrical Appliances—Safety—Part 2-40.*

[21] International Institute of Refrigeration (IIR), *Guidance on Safe Use of Flammable Refrigerants*, 2023.

[22] Badan Standardisasi Nasional (BSN), SNI ISO 5149..

[23] Kementerian Ketenagakerjaan Republik Indonesia, SKKNI Teknisi Refrigerasi dan Tata Udara (edisi terbaru yang berlaku).

[24] UNEP, *Global Cooling Watch Report*, 2023.

[25] International Labour Organization (ILO), *Occupational Safety and Health Guidelines for Refrigeration and Air Conditioning Technicians*, 2022.

[26] Mota-Babiloni et al., *Applied Sciences*, 2021.

[27] Ghanbarpour et al., *International Journal of Refrigeration*, 2022.

[28] Ibrahim et al., *Cleaner Engineering and Technology*, 2024.

[29] M. J. Page, J. E. McKenzie, P. M. Bossuyt, *et al*., "The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews," *The BMJ*, vol. 372, p. n71, 2021