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A Review on Investigating Eco-Friendly Alternatives to Traditional Refrigerants: Addressing Global Warming and Ozone Layer Depletion

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Abstract

The increasing environmental concerns related to traditional refrigerants, particularly hydrofluorocarbons (HFCs), have spurred global efforts to identify and adopt eco-friendly alternatives. Traditional refrigerants, while effective in cooling applications, are major contributors to global warming due to their high Global Warming Potential (GWP) and Ozone Depletion Potential (ODP). This paper investigates various eco-friendly refrigerants, including natural refrigerants like ammonia (NH3), carbon dioxide (CO2), and hydrocarbons (e.g., propane and isobutane), as well as synthetic low-GWP alternatives like hydrofluoroolefins (HFOs). These alternatives are compared across several criteria, including efficiency, environmental impact, safety, cost, and regulatory compliance. The analysis highlights that while eco-friendly refrigerants offer significant environmental benefits, their adoption faces challenges such as infrastructure compatibility, safety concerns, and higher initial costs. However, ongoing research, technological advancements, and supportive policy frameworks are poised to overcome these barriers, making the widespread adoption of sustainable refrigerants a feasible and necessary step toward mitigating climate change and protecting the ozone layer. This paper concludes by emphasizing the need for continued innovation, international collaboration, and public awareness to accelerate the transition to eco-friendly refrigerants, thereby ensuring a more sustainable future for refrigeration and air conditioning technologies.

Keywords:
Chlorofluorocarbons, Hydrochlorofluorocarbons, Ozone Layer Depletion, Global Warming, Eco-Friendly Refrigerants, Montreal Protocol, Kyoto Protocol.

1. Introduction

The refrigeration and air conditioning (AC) sectors play a pivotal role in modern society, providing essential services across various industries, including food preservation, healthcare, and comfort cooling in residential and commercial buildings. However, the widespread use of traditional refrigerants, particularly hydrofluorocarbons (HFCs), has raised significant environmental concerns due to their high global warming potential (GWP) and association with climate change. HFCs, while designed as replacements for ozone-depleting substances such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), are potent greenhouse gases with GWP values often thousands of times greater than carbon dioxide (CO2).

Recognizing the detrimental effects of HFCs on the environment, international efforts have intensified to phase them out under the Kigali Amendment to the Montreal Protocol. This global treaty aims to reduce the consumption and production of HFCs, prompting a critical need for effective and sustainable alternatives. The transition to eco-friendly refrigerants is essential not only to mitigate global warming but also to ensure the long-term health of the ozone layer.

This review paper explores the landscape of eco-friendly refrigerant alternatives, focusing on both natural and synthetic options. It assesses their environmental impact, efficiency, safety, and the regulatory frameworks that influence their adoption. By synthesizing current research and findings, this paper aims to highlight viable solutions for the refrigeration and AC sectors, addressing the pressing

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challenges posed by climate change and ozone depletion. The exploration of these alternatives is not merely a technical necessity but a vital step toward a sustainable future, balancing the needs of industry with the imperative of environmental stewardship.

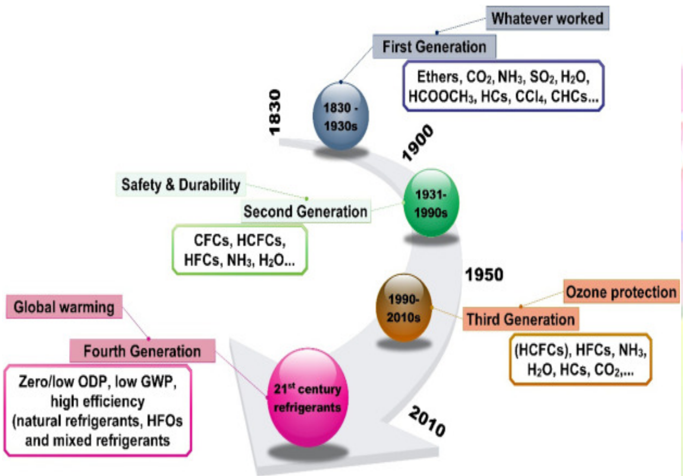

Figure 1. Refrigerant Progression (James Calm et al. 2010)

1.1.The Montreal Protocol: From 1987 To Till Date

The Montreal Protocol has been updated to reflect current scientific knowledge and technological advancements. Initially focused primarily on the production and consumption of Chlorofluorocarbons (CFCs), the Protocol has been revised over time to address surplus chemicals and adjust phase-out schedules for various substances.Today, the Protocol outlines a clear plan for global reductions in the production and consumption of nearly 100 substances, including CFCs, HCFCs, methyl bromide, halons, and other ozone-depleting substances. The most recent update, the Kigali Amendment, was implemented in October 2016.

With the phased elimination of ozone-depleting substances, there is a growing need for new and safer refrigerants to replace them. The global community and industries have responded with significant research and innovation to develop suitable alternatives. As a result, many non-ozone-depleting substances have entered the market. Manufacturers have leveraged the transition away from ozone-depleting substances to enhance their technologies and develop new products with improved energy efficiency. In some instances, entirely new types of systems have been created, rather than finding direct substitutes, to achieve better performance and environmental benefits.

2. Environmental Impact of Traditional Refrigerants

The environmental impact of traditional refrigerants, particularly hydrofluorocarbons (HFCs), has become a critical concern due to their role in climate change and the overall degradation of the environment. This section outlines the specific effects of these substances on global warming and ozone layer depletion.

2.1. Hydrofluorocarbons (HFCs)

HFCs were developed as substitutes for ozone-depleting substances like CFCs and HCFCs, offering a solution that protects the ozone layer. However, their high GWP poses significant risks to the global climate. The GWP of HFCs can range from hundreds to thousands times that of CO2, leading to substantial contributions to greenhouse gas emissions. As HFC usage has increased, so has their cumulative impact on global warming.

The Intergovernmental Panel on Climate Change (IPCC) has highlighted that, without significant reductions, emissions from HFCs could contribute as much as 0.5°C to global warming by 2100. Additionally, HFC emissions are expected to rise sharply as demand for refrigeration and air conditioning continues to grow, particularly in developing countries.

2.2. Ozone Layer Depletion

While HFCs themselves do not deplete the ozone layer, the legacy of other traditional refrigerants, such as CFCs and HCFCs, has had devastating effects. These substances release chlorine atoms into the atmosphere, which catalyze the breakdown of

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ozone molecules, leading to thinning of the ozone layer. The consequences of ozone depletion are far-reaching, including increased ultraviolet (UV) radiation reaching the Earth's surface, which can lead to higher rates of skin cancer, cataracts, and other health issues, as well as adverse effects on ecosystems, agriculture, and wildlife.

2.3. Other Environmental Concerns

In addition to their contribution to global warming and ozone depletion, traditional refrigerants can pose other environmental risks:

Leakage and Emissions: Refrigerants can leak during operation, maintenance, and disposal, releasing potent greenhouse gases into the atmosphere. Such emissions are often unaccounted for in greenhouse gas inventories, exacerbating the climate impact.

Energy Consumption: Traditional refrigeration systems using HFCs often operate less efficiently than systems using eco-friendly alternatives, leading to higher energy consumption. Increased energy use not only contributes to higher greenhouse gas emissions from fossil fuel power plants but also increases operational costs.

End-of-Life Management: The disposal of equipment containing HFCs can lead to environmental hazards if not properly managed. Improper disposal can result in the release of these gases into the atmosphere, further contributing to their harmful effects.

2.4. Regulatory Responses

In response to the environmental impact of traditional refrigerants, regulatory frameworks such as the Montreal Protocol have been established to phase out the use of ozone-depleting substances. The Kigali Amendment specifically addresses the phasedown of HFCs, encouraging countries to adopt more sustainable refrigerants. As awareness of the environmental consequences of these substances grows, additional regulations and incentives are expected to drive the transition to eco-friendly alternatives.

3. Eco-Friendly Alternatives

In response to the environmental challenges posed by traditional refrigerants, various eco-friendly alternatives have been developed. These alternatives can be broadly categorized into natural refrigerants and low-global warming potential (GWP) synthetic options. This section explores these alternatives, discussing their properties, benefits, and potential applications.

3.1. Natural Refrigerants

Natural refrigerants are substances that occur in nature and have minimal environmental impact. They include ammonia, carbon dioxide, and hydrocarbons.

Ammonia (NH_3):

Properties: Ammonia has a high cooling capacity and excellent thermodynamic efficiency, making it highly effective for industrial refrigeration systems.
Environmental Benefits: With a GWP of zero and no ozone depletion potential (ODP), ammonia is an environmentally friendly option.
Challenges: Its toxicity poses safety concerns, particularly in residential applications. Proper handling and safety measures are essential to mitigate these risks.
Applications: Ammonia is widely used in industrial refrigeration, large commercial chillers, and food processing industries.

Carbon Dioxide (CO_2):

Properties: CO_2 has a GWP of 1, making it one of the most environmentally benign refrigerants. It operates efficiently in transcritical cycles at higher ambient temperatures.

Environmental Benefits: CO_2 is non-toxic and non-flammable, offering a safe alternative for many applications.
Challenges: CO_2 systems require high-pressure equipment and specialized designs, which may increase initial costs.
Applications: CO_2 is increasingly used in supermarkets, beverage coolers, and heat pumps, especially in regions with stringent regulations on HFCs.

Hydrocarbons (Propane, Isobutane):
Properties: Hydrocarbons, such as propane (R290) and isobutane (R600a), have low GWP values and high energy efficiency.
Environmental Benefits: They possess no ozone depletion potential and are derived from renewable resources, making them a sustainable choice.
Challenges: Flammability is a major concern, necessitating strict safety standards and precautions in their use.
Applications: Hydrocarbons are commonly used in domestic refrigerators, freezers, and small commercial refrigeration systems.

3.2. Low-GWP Synthetic Alternatives
Synthetic refrigerants with low GWP values have been developed to replace HFCs while minimizing environmental impact. These include hydrofluoroolefins (HFOs) and blends.

Hydrofluoroolefins (HFOs):
Properties: HFOs are designed to replace HFCs with significantly lower GWP values (typically below 1). For example, HFO-1234yf has a GWP of less than 1.
Environmental Benefits: HFOs are considered more environmentally friendly than HFCs, as they break down more quickly in the atmosphere and have lower climate impact.
Challenges: While HFOs are generally safer than HFCs, their long-term effects on the environment and human health require further study.
Applications: HFO-1234yf is commonly used in automotive air conditioning systems, while HFO-1336mzz is being explored for commercial refrigeration.

Blends:
Properties: Refrigerant blends combine multiple refrigerants to achieve desirable properties, including lower GWP and improved efficiency.
Environmental Benefits: By blending lower-GWP refrigerants with HFCs, manufacturers can significantly reduce overall GWP while maintaining performance.
Challenges: The performance of blends can vary based on the specific ratio of components, and there is a need for careful management to prevent issues related to fractionation.
Applications: Blends are often used in commercial refrigeration and HVAC systems, providing flexibility and performance optimization.

4. Comparative Analysis of Alternatives
This section provides a comparative analysis of eco-friendly refrigerants, focusing on their efficiency, environmental impact, safety, and regulatory considerations. Understanding the strengths and weaknesses of each alternative is essential for making informed choices in various applications.

4.1. Efficiency and Performance
Ammonia (NH_3):
Efficiency: Ammonia is known for its high energy efficiency and excellent thermodynamic properties, making it highly effective in large-scale refrigeration systems.
Performance: Its cooling capacity is significantly higher than many HFCs, but its performance can be influenced by temperature and pressure conditions.

Carbon Dioxide (CO_2):
Efficiency: CO_2 systems operate efficiently in transcritical cycles, especially in moderate to high

ambient temperatures. However, at low temperatures, efficiency may drop.

Performance: The performance of CO2 is highly dependent on the system design and operational parameters, making it more suited for specific applications like commercial refrigeration.

Hydrocarbons (Propane, Isobutane):

Efficiency: Hydrocarbons exhibit high efficiency and are comparable to HFCs in terms of cooling performance, particularly in small and medium-sized systems.

Performance: Their performance is often enhanced in domestic refrigeration applications, where energy consumption can be significantly lower than that of traditional refrigerants.

Hydrofluoroolefins (HFOs):

Efficiency: HFOs, such as HFO-1234yf, are designed to mimic the performance of HFCs, providing efficient cooling while having lower GWP.

Performance: HFOs perform well in a variety of applications, including automotive air conditioning, and are compatible with existing HFC systems, facilitating retrofitting.

Blends:

Efficiency: Refrigerant blends can be engineered for improved efficiency by combining the properties of different refrigerants, allowing for tailored performance.

Performance: Blends may show varying performance based on the composition, requiring precise management during operation to prevent issues like fractionation.

4.2. Environmental Impact

Ammonia (NH3):

GWP: 0 (no contribution to global warming)

ODP: 0 (no ozone depletion potential)

Environmental Impact: Ammonia has minimal environmental impact, but its toxicity requires careful handling to prevent releases into the atmosphere.

Carbon Dioxide (CO2):

GWP: 1 (minimal climate impact)

ODP: 0 (no ozone depletion potential)

Environmental Impact: CO2 is environmentally benign, but its high-pressure systems can pose design challenges.

Hydrocarbons (Propane, Isobutane):

GWP: 3 (propane) / 3 (isobutane) (very low impact)

ODP: 0 (no ozone depletion potential)

Environmental Impact: Hydrocarbons have low environmental impacts, but their flammability requires strict safety measures.

Hydrofluoroolefins (HFOs):

GWP: < 1 (significantly lower than HFCs)

ODP: 0 (no ozone depletion potential)

Environmental Impact: HFOs are considered a significant improvement over HFCs; however, their long-term environmental effects are still being studied.

Blends:

GWP: Varies based on components (typically lower than HFCs)

ODP: 0 (no ozone depletion potential)

Environmental Impact: Blends can significantly reduce GWP but require careful consideration of the life-cycle impacts of all components involved.

4.3. Safety and Regulatory Compliance

Ammonia (NH3):

Safety: Ammonia is toxic and requires strict safety protocols to prevent leaks. It is not suitable for residential use without specialized systems.

Regulatory Compliance: Subject to regulations regarding its use, storage, and transportation, especially in industrial applications.

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Carbon Dioxide (CO_2):

Safety: CO2 is non-toxic and non-flammable; however, its high pressure requires specific design considerations to ensure safety.

Regulatory Compliance: CO2 systems must comply with pressure vessel regulations and safety standards, especially in commercial applications.

Hydrocarbons (Propane, Isobutane):

Safety: Hydrocarbons are flammable and require careful handling, installation, and maintenance to minimize risks.

Regulatory Compliance: Governed by safety regulations that mandate leak detection, ventilation, and appropriate refrigerant management practices.

Hydrofluoroolefins (HFOs):

Safety: HFOs have low toxicity but may have flammable characteristics that need to be addressed in system design and operation.

Regulatory Compliance: Subject to regulations similar to those for HFCs, with a growing emphasis on proper disposal and management to minimize environmental impact.

Blends:

Safety: The safety profile depends on the specific components; some blends may be flammable or toxic.

Regulatory Compliance: Blends must meet the regulatory requirements of all individual components, complicating compliance and management.

5. Challenges to Adoption

The transition to eco-friendly refrigerants presents several challenges that can hinder widespread adoption. These challenges encompass technical, economic, regulatory, and social dimensions. Addressing these barriers is crucial for facilitating the successful implementation of sustainable refrigeration and air conditioning solutions.

5.1. Infrastructure and Equipment Compatibility

Existing Systems: Many existing refrigeration and air conditioning systems are designed for traditional refrigerants like HFCs. Retrofitting or replacing these systems to accommodate eco-friendly alternatives can be complex and costly.

Equipment Design: Natural refrigerants often require specialized equipment and system designs due to differences in pressure, temperature, and lubrication properties. For instance, ammonia systems necessitate additional safety measures because of its toxicity, while CO2 systems operate at higher pressures, which can complicate design and installation.

Availability of Replacement Components: The market for components compatible with natural refrigerants, such as compressors and heat exchangers, may be limited, making it difficult for manufacturers to source necessary parts.

5.2. Public Perception and Acceptance

Safety Concerns: Public perception of safety is a significant barrier, particularly for natural refrigerants like ammonia and hydrocarbons, which can be perceived as hazardous. This perception may deter consumers and businesses from adopting these alternatives.

Lack of Awareness: Many stakeholders, including consumers, manufacturers, and contractors, may lack awareness of the benefits and safety of eco-friendly refrigerants. Educational initiatives are necessary to inform them about the advantages of these alternatives.

Industry Resistance: Industries accustomed to traditional refrigerants may resist change due to concerns about performance, cost, and reliability. This resistance can slow the transition to more sustainable options.

5.3. Cost Considerations

Initial Investment: The upfront costs associated with transitioning to eco-friendly refrigerants can be significant. This includes expenses related to

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equipment replacement, system redesign, and retrofitting existing systems.

Operational Costs: While many eco-friendly refrigerants offer improved energy efficiency, the initial costs may not be immediately recouped through energy savings. Businesses may be hesitant to invest in alternatives if short-term savings are not apparent.

Incentives and Support: The lack of sufficient government incentives or financial support for adopting eco-friendly technologies can be a major barrier, particularly for small and medium-sized enterprises (SMEs) that may struggle to bear the costs of transitioning.

5.4. Regulatory and Standards Challenges

Evolving Regulations: The regulatory landscape for refrigerants is constantly changing, with new laws and agreements aimed at reducing HFC use and promoting eco-friendly alternatives. This evolving environment can create uncertainty for manufacturers and businesses trying to comply with regulations.

Compliance Costs: Navigating regulatory requirements can be complex and costly, particularly for smaller businesses that may lack the resources to ensure compliance with safety, environmental, and operational standards.

Lack of Standardization: The absence of standardized protocols for handling and using natural refrigerants can create challenges for manufacturers and technicians. This lack of standardization can lead to inconsistencies in performance and safety across different systems and regions.

5.5. Technological Limitations

Performance Variability: Some eco-friendly refrigerants, particularly natural refrigerants, may not perform as well in certain applications or conditions compared to traditional refrigerants. This variability can limit their attractiveness for specific uses.

Technical Expertise: The adoption of new refrigerants often requires specialized knowledge and training for technicians and engineers. A lack of expertise in handling and maintaining systems that use eco-friendly alternatives can hinder their implementation.

Research and Development Needs: Ongoing research and development are needed to improve the performance and safety of eco-friendly refrigerants. This includes developing new technologies and methodologies that enhance their viability in diverse applications.

Findings of the present work are:

1. To study the performance of HFC152a/HC290/HC600 refrigerant mixture and compare the same with that of HCFC- 22 to attain an optimal mixture composition.

2. To investigate experimentally the performance of R- 152a/HCs refrigerant mixture with various compositions of HC blend and to optimize the same in the aspect of retrofitting and energy efficiency in a window air conditioner.

3. To carry out an economic study to analyse the effects of replacing R-22 with M3 in terms of energy savings and cost benefits.

7. Conclusion

The transition from traditional refrigerants to eco-friendly alternatives is critical for mitigating climate change and protecting the ozone layer. The environmental challenges posed by high-GWP refrigerants, such as HFCs, underscore the urgency of this shift. Eco-friendly alternatives, including natural refrigerants like ammonia, carbon dioxide, and hydrocarbons, as well as low-GWP synthetic options such as HFOs, offer viable pathways to reduce greenhouse gas emissions and enhance sustainability in the refrigeration and air conditioning sectors.

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Despite the clear benefits of these alternatives, several challenges remain, including technical compatibility, safety concerns, cost implications, and evolving regulatory frameworks. Addressing these barriers will require coordinated efforts among policymakers, manufacturers, industry stakeholders, and consumers. Research and development will play a pivotal role in driving innovation and improving the performance of eco-friendly refrigerants, while education and awareness initiatives can foster acceptance and demand.

Looking ahead, the future of refrigeration and air conditioning lies in the integration of sustainable practices, smart technologies, and collaborative efforts across the industry. By prioritizing eco-friendly alternatives, we can significantly reduce the environmental impact of cooling technologies and contribute to a more sustainable and resilient planet. The journey toward adopting eco-friendly refrigerants is not just a technical necessity but a crucial step toward achieving global climate goals and ensuring a healthier environment for future generations.

References

1. United Nations Environment Programme (2020). *Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer*. Retrieved from www.unep.org

2. Intergovernmental Panel on Climate Change (IPCC) (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press.

3. Global Climate Change Alliance (2019). *Reducing HFCs: The Role of Refrigerants in Climate Change*. Retrieved from www.gcca.org

4. US Environmental Protection Agency (EPA) (2020). *Protecting the Ozone Layer and the Global Climate System: Issues and Options*. Retrieved from www.epa.gov

5. De Grassi, A., & De Gennaro, C. (2020). "The Role of Natural Refrigerants in Sustainable Development." *Renewable and Sustainable Energy Reviews*, 121, 109646. doi:10.1016/j.rser.2019.109646

6. Wang, Y., & Zhang, J. (2021). "A Review of Hydrofluoroolefins (HFOs) as Alternative Refrigerants: Properties, Applications, and Safety." *Refrigeration Science and Technology*, 125, 76-89. doi:10.1016/j.rst.2021.100090

7. International Institute of Refrigeration (IIR) (2019). *Natural Refrigerants: The Future of Cooling*. Retrieved from www.iifiir.org

8. European Commission (2022). *F-Gas Regulation: Reducing HFCs to Combat Climate Change*. Retrieved from ec.europa.eu

9. ASHRAE (2019). *ASHRAE Position Document on Refrigerants*. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Retrieved from www.ashrae.org

10. Choi, J., & Kim, Y. (2020). "Energy Efficiency and Environmental Impact of Refrigeration Systems: An Overview of the Alternatives." *Energy Reports*, 6, 100-113. doi:10.1016/j.egyr.2020.11.010

11. Refrigerant Global (2023). "The Future of Refrigerants: Trends, Challenges, and Innovations." Retrieved from www.refrigerantglobal.com

12. World Refrigeration Day (2021). "Refrigeration and Air Conditioning: The Future is Green." Retrieved from www.worldrefrigerationday.org

13. Adrián Mota-Babiloni, Joaquín Navarro-Esbrí, Ángel Barragán- Cervera, Francisco Molés & Bernardo Peris 2015, 'Analysis based on EU Regulation No 517/2014 of new HFC/HFO mixtures as alternatives of high GWP refrigerants in refrigeration and HVAC systems', International Journal of Refrigeration.

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14. Adriano Greco, Mastrolla, R & Palombo 2003, 'R-407C as an Alternative to R-22 in Vapour Compression Plant: An Experimental Study', International Journal of Refrigeration, vol. 21, pp. 1087-1098.

15. Agarwal, RS & Bhatia, P 1998, 'Energy Consumption of Indian Domestic Refrigeration under Field and Laboratory Conditions A Step Towards Energy-Efficiency Standards', IIf-IIR Commissions, New Delhi, pp. 342-352.

16. Agarwal, RS 1998, 'Hydrocarbon Refrigerants for Domestic and Commercial Refrigeration Appliances', IIF-I1R Commissions, New Delhi, pp. 270-284.

17 Aprea, C & Greco, A 2013, 'Performance Evaluation of R-22 and R- 407C in a Vapour Compression Plant with Reciprocating Compressor', Applied Thermal Engineering, vol. 23, pp. 215-227.

18. Aprea, C, Mastrolla, R, Renno, C & Vanoli, GP 2004, 'An evaluation of R-22 Substituents Performance Regulating Continuously the Compressor Refrigeration Capacity', Applied Thermal Engineering, vol. 24, pp. 127-139.

19. Arcaklioglu, E 2005, 'An algorithmic approach towards finding better substitutes of Chlorofluorocarbons in terms of the second law of thermodynamics', Energy Conversion and Management, vol. 46, pp. 1595-1511.

20. Buero of Indian Standards (BIS) 1992, 'Room Air conditioners Specifications', Part I: Unitary Air Conditioners, IS1391, New Delhi, India.

21. Calm, JM & Domanski, PA 2004, 'R22 replacement status', ASHRAE J, vol. 46, no. 8, pp. 29-39.

22. Camporees, R, Bigolaro, G & Bobbo, S 1997, 'Experimental Evaluation of Refrigerant Mixtures as Substitutes for R-12 and R-502', InternationalJournal of Refrigeration, vol. 20, pp. 22-31.

23. Chen, S., Judge, JF, Groll, EA & Radermacher, R 1994, 'Theoretical Analysis of Hydrocarbon Refrigerant Mixtures as a Replacement for R- 22 for Residential Uses', International Refrigeration Conference, Indiana, pp. 225-230.

24. Choi, JM & Kim, YC 2002, 'The Effects of Improper Refrigerant charge on the Performance of a Heat Pump with an Electronic Expansion Valve and Capillary Tube', Energy, vol. 27, pp. 391-404.

25. 'Climate Change 2013: The physical science basis. Contribution of working group I to the fifth Assessment Report of the Intergovernmental panel on Climate Change (IPCC), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

26. Corberan, JM & Segurado, JB 2008, 'Review of standards for the use of hydrocarbons refrigerants (HCs) in air conditioners, heat pump and refrigeration equipment', International Journal of Refrigeration, vol. 3, no. 4, pp. 748-756.

27. Coulbourne, D & Ritter, TJ 1998, 'Hydrocarbon Refrigeration Safety: Standards and Quantitative Risk Assessments', IIF-IIR Commissions Conference, New Delhi, pp. 293-301.

28. David Morrison, J, Stuat Corr & Bruce E Gillbert 1997, 'Production Scale Handling of Zeotropic Blends' ASHRAE Transactions, vol. PH- 97-9-2, pp. 756-764.

29. Deng, J 1989, 'Introduction to Grey Theory', Journal of Grey Systems, vol. 1, no. 1, pp. 1-24.

30. Devotta, S, Padalkar, AS & Sane, NK 2005, 'Performance assessment of HC290 as a drop-in substitute to HCFC-22 in a window air conditioner', International Journal of Refrigeration, vol. 28, pp. 594-604.

31. Devotta, S, Patil, PA, Joshi, SN, Sawant, NN & Sane, NK 1998, 'Compressor Life tests with Alternatives to R-12', IIf-IIR Commissions, New Delhi, pp. 321-329.

32. Devotta, S, Waghjmare, AV, Sawant, NN & Domkundwar, BM 2001, 'Alternatives to R-22 for Air Conditioners', Applied Thermal Engineering, vol. 17, pp. 703-715.