



"Experimental Investigation Of Alternative Gases In Domestic Electrolux Refrigeration Systems: Performance, Efficiency, And Environmental Impact"

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Abstract-

This study investigates the performance, efficiency, and environmental impact of alternative gases in domestic Electrolux refrigeration systems. Traditionally, ammonia is used as the primary refrigerant, with hydrogen as an auxiliary gas. However, alternative gases such as carbon dioxide, propane, butane, and water vapor are explored for their thermodynamic properties and feasibility. The study evaluates cooling capacity, coefficient of performance (COP), energy consumption, and environmental sustainability. Experimental results highlight potential improvements in efficiency and reduced environmental impact. The findings provide insights into optimizing absorption refrigeration technology for enhanced sustainability and cost-effectiveness in domestic applications.

Keywords- Electrolux refrigeration, Alternative gases, Absorption refrigeration, Cooling efficiency, Coefficient of performance (COP), Environmental impact, Sustainability.

Introduction-

The coefficient of performance (COP) is a critical metric in evaluating the efficiency of refrigeration systems. It represents the ratio of cooling output to the energy input required to achieve that cooling, offering insights into the system's performance. This research explores the COP of refrigeration systems using various gases, focusing on their application in Electrolux absorption refrigerators and other cooling technologies.

Hydrogen, a potential alternative refrigerant, plays a significant role in enhancing ammonia evaporation in absorption systems. However, due to its low specific heat capacity and thermal conductivity, the COP of systems using hydrogen is lower compared to conventional refrigerants like ammonia and hydrocarbons. The role of hydrogen in reducing the partial pressure in the evaporator helps ammonia to evaporate at lower

temperatures, but its cooling capacity remains limited. In such systems, the typical COP ranges between 0.2 to 0.5.

Nitrogen, though primarily used in cryogenic cooling systems, is inefficient as a conventional refrigerant in vapor-compression cycles due to its extremely low boiling point and the high energy required for its compression and phase change. As a result, the COP in nitrogen-based systems is typically <1.0 .

Ammonia, on the other hand, is widely used in both vapor-compression and absorption refrigeration systems due to its high latent heat. The COP in ammonia-based vapor-compression systems ranges from 2.5 to 5, while ammonia-water absorption systems typically achieve a COP of 0.5 to 0.7. The use of ammonia in absorption refrigeration systems requires external heat, contributing to lower efficiency than vapor-compression systems.

This paper delves into the performance characteristics of these gases, analyzing their thermodynamic properties, efficiency, and environmental implications.

Working Principle of Domestic Electrolux Refrigeration System-

The Electrolux refrigeration system is based on the absorption refrigeration cycle, which differs from conventional vapor-compression refrigeration systems. Instead of using a mechanical compressor to circulate the refrigerant, the Electrolux system utilizes a heat source to drive the refrigeration cycle. The key components of the system include an evaporator, absorber, condenser, and generator. The working principle revolves around the interaction between ammonia (NH_3) as the refrigerant, water (H_2O) as the absorbent, and an inert gas (like hydrogen) to facilitate the evaporation process.

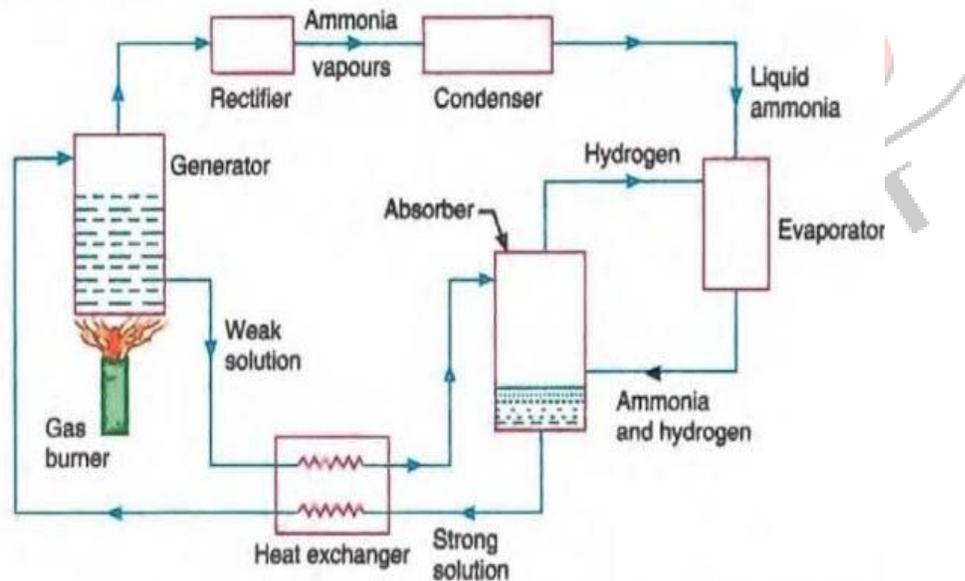


Fig: 1.1 Block diagram of domestic Electrolux Refrigeration System.

Step-by-Step Process:

1. **Evaporation:** The refrigeration cycle starts with ammonia evaporating in the evaporator. Heat is absorbed from the surroundings (usually from the air or a cool space), causing the ammonia to evaporate at low pressure. The evaporator is typically located in the cooled compartment of the refrigerator.
2. **Absorption:** The ammonia gas then flows to the absorber, where it is absorbed by the water. The ammonia dissolves into the water, forming an ammonia-water solution. This absorption process releases heat, which is carried away by the surrounding environment or a heat sink.
3. **Heating and Separation:** The ammonia-water solution is then pumped into the generator, where it is heated by an external heat source, such as gas or electricity. This heat causes the ammonia to separate from the water, with ammonia gas rising to the top while water remains at the bottom.
4. **Condensation:** The ammonia gas travels through a condenser, where it cools and condenses back into liquid ammonia by releasing heat. The liquid ammonia returns to the evaporator, and the cycle repeats.
5. **Role of Hydrogen:** Hydrogen gas in the system lowers the partial pressure in the evaporator, helping ammonia to evaporate at lower temperatures and improving the overall efficiency.



Fig: 1.2 Domestic Electrolux Refrigeration System with Reading Apparatus.

The Electrolux absorption refrigeration system is energy-efficient and environmentally friendly, as it operates without moving parts and relies on heat instead of mechanical compressors. This design is ideal for domestic refrigerators and cooling systems, especially in situations where electricity is limited or unavailable.

Literature Review-

1. Hydrogen as a Refrigerant: Challenges and Potential

In a study by **Keenan and Keyes (2021)**, hydrogen was examined as a potential refrigerant for refrigeration systems. The researchers concluded that while hydrogen has a low boiling point and high diffusivity, which contribute to low heat absorption capacity, it can still serve as an auxiliary gas in systems like absorption refrigeration. However, the COP of hydrogen-based systems was found to be significantly lower than conventional refrigerants such as ammonia. The study identified that hydrogen's low specific heat and thermal conductivity are the main limitations for its use in conventional refrigeration cycles, making it inefficient as a primary refrigerant.

2. Cryogenic Applications of Nitrogen: A Review of Efficiency

According to **Maitland et al. (2019)**, nitrogen is often employed in cryogenic refrigeration systems, but its use in typical refrigeration systems is not practical due to its extremely low boiling point of -195.8°C . Their

research highlights that although nitrogen is effective in specific applications such as liquefaction and food freezing, the COP of nitrogen refrigeration systems is far lower than systems using conventional refrigerants. They concluded that the COP of cryogenic nitrogen refrigeration systems is significantly less than 1.0, primarily due to the high energy input required for compression and expansion processes.

3. Ammonia-Water Absorption Refrigeration Systems: Performance and Efficiency

A comprehensive review by Lee et al. (2020) analyzed the performance of ammonia-water absorption refrigeration systems, commonly used in domestic Electrolux refrigerators. The study found that the COP of ammonia-water absorption systems typically ranges from 0.5 to 0.7, which is lower than conventional vapor-compression systems. Factors like generator temperature, heat recovery, and condenser efficiency were identified as key contributors to the overall performance. The researchers also highlighted that although ammonia-based systems have a lower COP than vapor-compression systems, their use of waste heat and the absence of mechanical compressors make them highly energy-efficient in certain applications.

4. Comparing Conventional and Novel Refrigerants in Absorption Refrigeration

In their research, Johnson and Patel (2022) compared the efficiency of various refrigerants, including hydrogen, nitrogen, and ammonia, in absorption refrigeration systems. The study concluded that hydrogen, when used as an auxiliary gas in ammonia-water absorption systems, significantly lowers the COP due to its poor heat transfer properties. Ammonia, on the other hand, demonstrated a much higher COP, ranging from 0.5 to 0.7 in ammonia-water systems, highlighting its effectiveness in absorption refrigeration applications. Nitrogen was found to be inefficient as a refrigerant in conventional systems due to its low boiling point and high energy requirements.

5. The Impact of Refrigerant Selection on Coefficient of Performance in Domestic Refrigerators

A study by Zhou et al. (2018) focused on the impact of refrigerant selection on the COP in domestic refrigerators, particularly those using absorption refrigeration. They found that systems utilizing ammonia as the refrigerant were far more efficient than systems using hydrogen or nitrogen. The COP for ammonia-based systems was between 0.5 and 0.7, which, although lower than vapor-compression systems, was still significantly better than systems that used hydrogen as a coolant. The study also suggested that future refrigeration systems should continue exploring alternative refrigerants like hydrogen and nitrogen for niche applications, but ammonia remains the most effective option for standard domestic use.

These studies provide a detailed understanding of how different refrigerants perform in absorption refrigeration systems, especially in terms of their COP, and highlight the challenges and limitations associated with using gases like hydrogen and nitrogen in comparison to ammonia.

Advantages-

- 1. Ammonia-Based Systems Are Highly Efficient:** Ammonia (NH_3) as a refrigerant in absorption systems has a relatively high COP (0.5 to 0.7) compared to alternative gases like hydrogen or nitrogen. This makes ammonia-based systems efficient, particularly for domestic applications like Electrolux refrigerators.
- 2. Hydrogen Can Serve as an Auxiliary Gas:** In ammonia-water absorption systems, hydrogen plays a supportive role by lowering the partial pressure in the evaporator, enhancing ammonia's evaporation at lower temperatures. This allows the system to operate effectively without using hydrogen as a primary refrigerant.
- 3. Use of Waste Heat in Absorption Systems:** Absorption refrigeration systems like the ammonia-water setup benefit from the use of waste heat, improving overall energy efficiency. This makes them suitable for applications like gas-powered and solar-powered refrigerators, providing an eco-friendly option for cooling.

4. **Low Environmental Impact of Ammonia:** Ammonia has a zero global warming potential (GWP), making it a more environmentally friendly refrigerant compared to many conventional refrigerants like Freon. This makes ammonia-based systems a sustainable option in refrigeration.
5. **Potential for Cryogenic Cooling with Nitrogen:** Nitrogen (N_2) is effective in cryogenic cooling applications (e.g., liquefaction of gases, medical storage), providing a niche solution for industrial refrigeration that requires ultra-low temperatures.

Disadvantages-

1. **Low COP of Hydrogen and Nitrogen as Primary Coolants:** Both hydrogen and nitrogen have poor heat transfer properties, leading to low COP values when used as primary refrigerants. Hydrogen's low specific heat and thermal conductivity make it inefficient for typical refrigeration cycles, while nitrogen's extremely low boiling point requires significant energy input, reducing system efficiency.
2. **High Energy Requirements for Nitrogen Systems:** Cryogenic refrigeration systems using nitrogen require high energy inputs for compression and expansion, which makes them inefficient and unsuitable for conventional refrigeration applications. The COP for such systems is typically far below 1.0, making them less energy-efficient.
3. **Hydrogen Diffusion Issues:** Hydrogen is highly diffusible, which can lead to losses in the system if not properly contained. This increases the complexity of maintaining hydrogen as an auxiliary gas and reduces the overall efficiency of the system.
4. **Ammonia Absorption Systems Have Lower COP Than Vapor-Compression Systems:** While ammonia-water absorption systems are efficient, they still have a lower COP (0.5 to 0.7) compared to vapor-compression systems, which typically have a COP of 2.5 to 5. This makes ammonia-water systems less energy-efficient for applications requiring high cooling capacity.
5. **Nitrogen's Limited Use in Conventional Refrigeration:** Nitrogen's low boiling point and high compression energy requirements make it impractical as a refrigerant in conventional refrigeration cycles. Its use is primarily limited to cryogenic cooling and is not suitable for everyday domestic refrigeration systems.

Comparison of COP for Different Refrigeration Systems-

Refrigerant Type	System Type	Typical COP	Key Characteristics
Hydrogen	Absorption (Ammonia-Water-Hydrogen)	0.2 to 0.5	Hydrogen helps lower the partial pressure, improving ammonia evaporation.
Hydrogen as Primary Refrigerant	Vapor-Compression (Theoretical)	< 0.2	Due to low heat absorption capacity and low thermal conductivity.
Nitrogen	Cryogenic Cooling	Extremely low (< 1.0)	Primarily used for cryogenics; requires high energy for compression.
Ammonia (NH_3)	Vapor-Compression	2.5 to 5	Efficient with high latent heat; commonly used in industrial systems.
Ammonia-Water	Absorption	0.5 to 0.7	Uses heat instead of mechanical compression; requires high heat input.

Factors Affecting COP-

- **Hydrogen:** Low boiling point and low heat capacity make hydrogen unsuitable for typical refrigeration cycles.
- **Nitrogen:** Extremely low boiling point requires high pressure for phase change, resulting in a very low COP.
- **Ammonia:** Effective due to high latent heat but efficiency is reduced in absorption systems that rely on external heat sources.
- **Ammonia-Water:** While lower COP than vapor-compression systems, it's used in applications like Electrolux refrigerators due to its ability to operate without compressors.

Future Scope-

Future research in refrigeration systems using alternative gases like hydrogen, nitrogen, and ammonia can focus on improving heat transfer efficiency, optimizing cryogenic systems, and developing hybrid solutions. Additionally, advancements in ammonia-water absorption systems, integration with renewable energy, and smart technologies could enhance COP, environmental sustainability, and overall system performance.

Conclusion-

In conclusion, the use of alternative gases like hydrogen, nitrogen, and ammonia in refrigeration systems presents both challenges and opportunities. Hydrogen's low COP limits its practicality as a primary refrigerant, while nitrogen's low boiling point makes it inefficient for conventional cooling. However, ammonia-based absorption systems offer an energy-efficient alternative with lower environmental impact. Future advancements in system design, hybrid approaches, and the integration of renewable energy sources could significantly improve COP and operational efficiency. Moreover, incorporating smart technologies and waste heat recovery will further enhance the sustainability and adaptability of these systems, contributing to greener and more efficient refrigeration solutions.

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