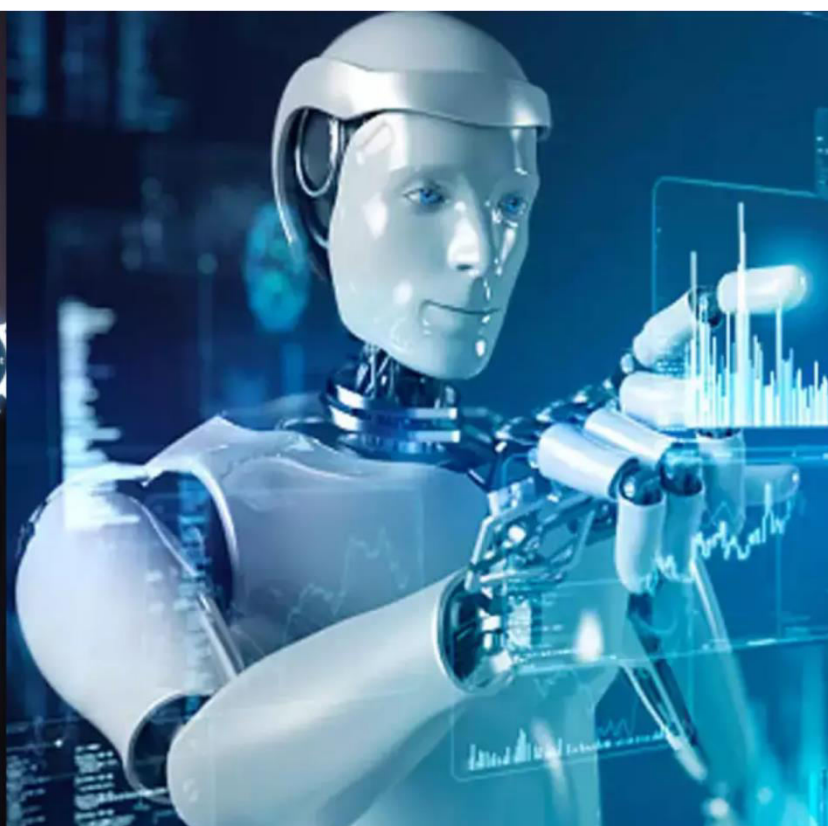




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Enhancing Heat Transfer Rate in Commercial Refrigerators: A Review

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ABSTRACT: In the food service and retail industries, commercial refrigerators play a crucial role in maintaining the quality and safety of perishable goods. One of the primary challenges in refrigeration systems is improving the heat transfer rate to enhance energy efficiency, reduce operational costs, and ensure rapid cooling or freezing of products. This paper explores several methods and technologies to enhance the heat transfer rate in commercial refrigerators, focusing on the optimization of heat exchangers, refrigerants, and system design. Various strategies, including the use of enhanced heat transfer surfaces, microchannel technology, phase-change materials (PCMs), and advanced refrigerants, are reviewed and discussed.

KEYWORDS: Heat Transfer Rate, Microchannel Heat Exchangers, Plate Heat Exchangers, Finned Tube Heat Exchangers, Refrigerants, Low-GWP Refrigerants, Supercritical Fluids, Surface Modification, Surface Roughening, Hydrophilic Coatings.

I. INTRODUCTION

Commercial refrigerators are essential in maintaining low temperatures for food storage, beverage cooling, and other industrial applications. In these systems, heat is absorbed from the interior of the refrigerator and transferred to the environment. The effectiveness of this heat transfer process determines the overall efficiency and performance of the refrigeration system. Therefore, improving the heat transfer rate in commercial refrigerators can significantly impact energy consumption, operational costs, and the lifetime of the equipment. This paper provides an overview of strategies and technologies that can be used to enhance heat transfer in commercial refrigerators. We will examine advances in heat exchanger designs, refrigerant choices, surface modifications, and system configurations, all of which contribute to better heat transfer performance. During the earliest attempts to enhance heat transfer, plain (or smooth) surfaces were used. This surface requires a special surface geometry able to provide higher efficiency. There are several available options for enhancing heat transfer. The enhancement can be achieved by increasing the surface area for convection or/and increasing the convection coefficient. For example, the surface roughness can be used to increase in order to enhance turbulence. This can be achieved through machining or other kinds of insertions like coil-spring wire. The insert provides a helical roughness in contact with the surface. The convection coefficient may also be increased by an insert of a twisted tape that consists in a periodical twist through 360 degrees. Tangential inserts optimize the velocity of the flow near the tube wall, while providing a bigger heat transfer area. While, increased area and convection coefficient can be achieved by applying spiral fin or ribs inserts. Other aspects such pressure drop must be taken into consideration in order to meet the fan or pump power constraints. Addition of nanoparticles changes the boiling characteristics of the base fluids. Nanoparticles can be used in refrigeration systems because of its remarkable improvement in thermophysical and heat transfer capabilities to enhance the performance of refrigeration systems.

II. LITERATURE SURVEY

In recent years, improving the heat transfer rate in commercial refrigeration systems has garnered significant attention. The optimization of heat transfer mechanisms is crucial for enhancing the energy efficiency, performance,

and sustainability of refrigeration systems. This literature survey reviews the key studies, advancements, and emerging technologies aimed at enhancing heat transfer in commercial refrigerators, focusing on heat exchanger designs, refrigerants, surface modifications, and system configurations. Microchannel heat exchangers (MHEs) have emerged as an effective technology for enhancing heat transfer in refrigeration systems. According to **Liu and Zhang (2019)** [1] MHEs, with their small internal channel sizes, present a high surface area-to-volume ratio, which improves convective heat transfer and minimizes refrigerant charge. The reduced channel diameter increases turbulence and enhances heat transfer performance significantly. Studies by **Koyama and Morita[2] (2015)** highlighted the effectiveness of microchannel heat exchangers in both evaporators and condensers, improving overall system performance by up to 30% compared to traditional finned-tube designs. Finned tube heat exchangers are widely used in commercial refrigeration systems, particularly for air-cooled condensers and evaporators. Enhanced fin geometries have been proposed to increase the heat transfer rate. In a study by **Kumar and Gupta[3] (2018)**, it was found that the use of extended fins significantly increases the heat transfer surface area, although this can lead to increased air pressure drop and energy consumption. **Liu and Zhang [4] (2019)** highlighted CO₂'s potential for both high thermal conductivity and efficient phase change behaviours in refrigeration systems. However, CO₂ systems often require specialized components, such as gas coolers and high-pressure equipment, which increases system cost.

The work in this paper is divided in two stages. 1) Detecting the problems regarding performance of refrigerator in commercial areas 2) Finding the solution to enhance performance.

III. METHODOLOGY

Enhancing the heat transfer rate in commercial refrigerators involves a combination of innovative designs, advanced materials, optimal operating conditions, and system configurations. The methodology to achieve improved heat transfer performance can be broken down into several key stages, including system design, material selection, and optimization techniques. Below is a detailed methodology for improving the heat transfer rate in commercial refrigerators. Heat exchangers are at the core of refrigeration systems, and their design is crucial for improving heat transfer efficiency. The methodology for enhancing heat transfer starts with the design and optimization of heat exchangers. Use microchannel heat exchangers, which consist of small, closely spaced channels that enhance the surface area-to-volume ratio. This increases turbulence and heat transfer coefficients (Microchannel Heat Exchangers (MHEs)). Use finned tube designs to increase the surface area of heat exchange and improve heat dissipation from the refrigerant (Finned Tube Heat Exchangers). Integrate plate heat exchangers, which are highly efficient in terms of heat transfer and compactness. Their stacked plate structure allows for efficient thermal exchange (Plate Heat Exchangers). Surface Roughening: Modify the surface of the heat exchanger (e.g., evaporator or condenser) to increase the roughness, which can increase turbulence and improve convective heat transfer. Use techniques such as laser engraving or coating the surfaces with rough textures to promote better heat exchange. Enhanced turbulence and heat transfer coefficient, though there may be a slight increase in pressure drop. Apply hydrophilic coatings on heat exchange surfaces to improve water film formation and enhance heat transfer, particularly in evaporators. Apply coatings such as silicon-based hydrophilic substances to evaporator fins or coils to ensure a more uniform distribution of the water film. Increased heat transfer rates in air-conditioning and refrigeration systems, while also reducing the potential for frost build-up.

IV. REVIEW AND SCENARIO

Heat Transfer Mechanisms in Refrigeration Systems through three primary mechanisms: conduction, convection, and radiation. Conduction is the transfer of heat through solid materials (such as the metal walls of the evaporator and condenser coils). Convection occurs as the heat is transferred between the fluid (air or refrigerant) and solid surfaces (evaporator and condenser coils). Radiation is the emission of energy as electromagnetic waves, though it is less significant in the context of refrigerator heat exchange compared to conduction and convection. The most critical factor in improving heat transfer in a refrigerator is to optimize the balance between conduction and convection at both the evaporator (cooling) and condenser (heat rejection) sides. Enhanced Heat Exchanger Designs One of the most effective ways to improve the heat transfer rate in commercial refrigerators is by optimizing the heat exchanger design. Several innovations have been made in heat exchanger technology, including: Microchannel Heat Exchangers (MHEs) consist of numerous small channels (microscopic in scale) that allow refrigerants to flow through compact passages. The reduced channel diameter results in a higher surface area to volume ratio, leading to improved heat transfer.

These systems are beneficial in both the evaporator and condenser sections of refrigeration systems. Plate Heat Exchangers consisting of multiple stacked plates with channels for refrigerant and airflow, offer a high surface area for heat transfer. This design enhances both thermal conductivity and heat transfer efficiency, particularly in applications where space is limited. Finned Tube Heat Exchangers are commonly used in air-cooled refrigeration systems. The use of extended surfaces (fins) increases the surface area for heat exchange between the refrigerant and air. Finned tube systems can be optimized through the use of advanced materials and fin geometries. Low cost, widely used, and effective for air cooling. Performance degradation due to dust and dirt accumulation on the fins, requiring frequent cleaning. Advanced Refrigerants, The choice of refrigerant has a significant impact on the heat transfer rate in a commercial refrigerator. Traditionally, refrigerants like R-22, R-134a, and R-404A were used, but with the growing demand for sustainability and efficiency, newer refrigerants are being considered. Low-GWP Refrigerants

The use of low Global Warming Potential (GWP) refrigerants, such as CO₂ (R-744), ammonia (R-717), and hydrofluoroolefins (HFOs), has been on the rise. These refrigerants have lower environmental impacts, but their thermodynamic properties must be well understood to optimize heat transfer efficiency. CO₂ (R-744): Offers high heat transfer efficiency at low temperatures, ideal for commercial refrigeration. Ammonia (R-717): Excellent thermodynamic properties and low environmental impact but requires careful handling due to toxicity and flammability. Supercritical Fluids exhibit unique thermophysical properties, such as high thermal conductivity and low viscosity, which contribute to improved heat transfer. Supercritical CO₂ is a promising refrigerant in refrigeration systems due to its enhanced heat exchange capabilities, especially in lower temperature applications. Surface Modification Techniques Improving the surface characteristics of heat exchangers can significantly enhance heat transfer performance. Some of the key methods include: Surface Roughening The roughening of heat exchanger surfaces (e.g., through the application of micro-structured surfaces or coatings) can enhance turbulence in the fluid, leading to better heat transfer. This technique increases the convection heat transfer coefficient by disrupting the boundary layer and enhancing mixing. Hydrophilic Coatings In refrigeration systems, especially in air-cooled units, the formation of water droplets on evaporator surfaces can improve heat transfer by increasing surface wettability.

Hydrophilic coatings allow for a uniform film of water to form on the surface, enhancing evaporation efficiency. Improves evaporator performance and reduces the chances of ice build-up. Challenges: Durability of coatings over time. Use of Phase Change Materials (PCMs) Phase Change Materials (PCMs) are substances that absorb or release large amounts of latent heat during phase transitions (e.g., from solid to liquid or vice versa). By incorporating PCMs into the refrigeration system, the cooling load can be balanced, reducing the strain on the compressor and enhancing overall heat transfer efficiency. Reduces compressor cycling, stabilizes temperature fluctuations, and improves efficiency. High initial cost and complexity in system integration. System Configuration and Optimization Beyond the components, optimizing the overall refrigeration system configuration is also essential for improving heat transfer efficiency. Strategies include: Variable Speed Compressors: Adjusting compressor speed based on cooling demand can optimize energy consumption and improve the overall efficiency of the system. Dual-Loop Systems: Using two separate loops for the refrigerant and air or water allows for better control and can optimize heat transfer performance. Energy Recovery Systems: Implementing heat recovery systems that capture and reuse waste heat from the refrigeration system can improve overall energy efficiency.

V. BENEFITS AND CHALLENGES

Increases convective heat transfer, Surface roughening may increase the pressure drop and energy consumption in the system. Improves evaporator performance and reduces the chances of ice build-up. Durability of coatings over time. Reduces compressor cycling, stabilizes temperature fluctuations, and improves efficiency. High initial cost and complexity in system integration. Adjusting compressor speed based on cooling demand can optimize energy consumption and improve the overall efficiency of the system. Using two separate loops for the refrigerant and air or water allows for better control and can optimize heat transfer performance. Implementing heat recovery systems that capture and reuse waste heat from the refrigeration system can improve overall energy efficiency.

VI. FUTURE SCOPE

The future scope of heat transfer enhancement in refrigerators is a promising and evolving field, driven by the need for energy efficiency, environmental sustainability, and improved performance. As technology advances and environmental regulations become stricter, the following areas represent the key future directions for heat transfer

enhancement in refrigeration systems like Advanced Computational Fluid Dynamics (CFD), Sustainability and Eco-friendly Design, Heat Pump Integration and Waste Heat Recovery, Smart Cooling Technologies, Thermoelectric Coolers (TECs) and Heat Pumps etc. It will be marked by advances in materials, refrigeration cycles, and integration with alternative technologies. These innovations will be driven by energy efficiency, sustainability, and the need to comply with stricter environmental regulations, positioning the industry for greener and more efficient cooling solutions.

VI. CONCLUSION

Depending on the benefits and future scopes of this project further statements are made like Enhancing the heat transfer rate in commercial refrigerators is a multifaceted approach involving improvements in heat exchanger designs, refrigerant selection, surface modifications, and system optimization. By adopting these advancements, commercial refrigerators can operate more efficiently, reduce energy consumption, and provide better performance in preserving perishable goods. As technologies continue to evolve, integrating microchannel heat exchangers, low-GWP refrigerants, surface-enhanced systems, and phase-change materials presents a promising pathway for the future of commercial refrigeration.

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