

Handbook of Research on

# Advances and Applications In Refrigeration Systems and Technologies



Pedro Dinis Gaspar and Pedro Dinho da Silva



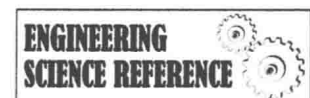
Volume I

# Handbook of Research on Advances and Applications in Refrigeration Systems and Technologies

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## Preface

Due to the growing political, economical and social concerns about energy consumption, in particular with the need to reduce greenhouse gas emissions and fossil fuel consumption, taking into account the sharp rise of energy costs in recent years, sustainability and competitiveness of industries depend, to some extent, on the ability to use energy rationally and efficiently. The refrigeration systems are widely used in domestic, commercial and industrial applications. Simultaneously, these systems are large energy consumers, specifically of electrical energy, besides presenting a global negative environmental impact. Therefore, there is a need to develop numerical and experimental research in order to promote the energy efficiency and to reduce the carbon footprint.

In terms of food cold chain, the sustainability and food safety are a major concern of consumers in recent years. There has been an increasing demand for foods as well as a change in consumption habits. To deal with this new trend, there is a greater availability and variety of food with longer shelf life. In this context, refrigeration plays an important role, not only for its ability to preserve the products with the maintenance of its physical, chemical, nutritional and organoleptic characteristics, but also because it is an indispensable tool for processing, distributing and storage of perishable foods.

In general, processes involving food products are carried out in artificial environments with strict control of air temperature, humidity and velocity, resulting in the use of systems which generate cold and heat, although cooling systems are the main responsible by the energy consumption.

To improve the refrigeration sustainability is necessary to pursue new technological and scientific advances on both processes and equipments, through their innovative designs. These designs configure improved vapor compression cycles and efficient heat and mass transfer processes that simultaneously can minimize the refrigerant charge. Commercial and industrial refrigeration require processing, transportation and storage in refrigerated environments. The improvement of the refrigeration process in these environments require a better understanding of the cold production itself, as well as the facilities design optimization, proper selection of devices and equipments, and the development and use of new refrigerants. These procedures allow ensuring food quality and safety both in commercial and industrial sectors, and the quality of specific products produced in the latter sector. Thus, research and development (R&D) in refrigeration is towards the development of sustainable technologies in order to reduce carbon footprint, mitigate climate change and improve energy efficiency. So, it includes the development of innovative and/or alternative cooling technologies and their novel concepts, associated with improved control and monitoring systems based on advanced techniques and technologies such as artificial intelligence and energy harvesting, respectively. These studies follow two main paths: experimental or numerical studies. The experimental studies involve the use of several equipment and techniques for measuring relevant

parameters variation. The other path require modeling and predicting the parameters variation through computational tools. These results of R&D in refrigeration can provide guidelines for new legislations, policies and strategies related to the energy efficiency, equipment safety and performance.

The Handbook of Research on Advances and Applications in Refrigeration Systems and Technologies identifies the main issues involving refrigeration processes and systems. It provides an introduction to refrigeration processes and systems and their advance due to the ongoing research, being not limited to these topics but exploring a wide span of applications, their technologies, equipments, procedures, environmental impact and energy concerns. Moreover, it aims to unveil trends and opportunities for the improvement of the sector's efficiency and its sustainability. The handbook reviews the state of the art and recent advances in several application areas of refrigeration systems. It covers specific subjects, from the difficulties that arise from the frost formation on the surface area of evaporators to the carbon footprint triggered from refrigerants use. Nevertheless, it also provide a board insight of refrigeration, focusing general aspects likewise optimization, sustainability and technology innovation in cold chains. At the same time, it is aimed to be a reference text presenting true implications of the use of refrigeration, its devices operation and research efforts to improve processes and systems efficiency.

The Handbook of Research on Advances and Applications in Refrigeration Systems and Technologies is organized in such a way that highlights both specific and general topics in order to provide its use to a large audience with refrigeration interest, from undergraduate students to researchers. It can be used in didactic context by under-graduate and graduate students, and in research context by post-graduate students and researchers. The practicing engineers can find in this book several topics that can be an added value to the selection, design and retrofit of refrigeration systems, equipments and facilities.

Although some topics are placed at a level that does not require considerable previous expertise in the technical details of specific areas, others are somehow knowledge demanding due to the complex research discussion.

The Handbook of Research on Advances and Applications in Refrigeration Systems and Technologies is organized into twenty-four chapters. The chapters present the recent research concerning refrigeration systems and applications and survey the state of the art in this field. The contributors review advances in processes and equipments design, efficient heat and mass transfer processes, optimization of real operating systems, modeling and predictive computational tools, innovative technologies, among others. A brief description of each of the chapters follows:

Chapter 1 describes a collaborative effort of US private companies and various departments of the US Government to investigate the possibility of improving the efficiency of HVAC systems by use of one and two-phase ejectors. The author anticipates that this technology, when fully developed, will result in attractive, energy saving products that significantly improve the performance of commercial and residential chiller/air-conditioning systems, refrigeration plants, and heat pumps (geothermal and air-source).

Chapter 2 presents the Diffusion Absorption Refrigerator (DAR) together with a new advanced thermodynamic model. The authors perform the validation of the model on a prototype built coupling a domestic 750 W-magnetron with a small purposely modified commercial DAR to activate the thermal pump.

Chapter 3 applies a conventional and advanced exergetic analysis to an air refrigeration machine. The authors argue that a conventional exergetic analysis does not consider the real potential for improving a system nor the interactions among the components of the system.



Chapter 4 reviews the basic mechanisms of static sublimation process and sublimation two-phase flows. The authors start to classify the previous studies into numerical modeling and experimental verifications and introduce and compare representative refrigeration systems. Future research focuses is then established.

Chapter 5 presents the development of ejector refrigeration technology. Authors suggest that this technology strongly reduces the greenhouse gases emission by using natural refrigerants and also dramatically reduces the need for the electric power. Authors contend that this is accomplished by using free or inexpensive heat – either solar or waste heat, as the main source of energy instead of electricity. The authors suggest that the operation of the ejection cycle using low-temperature heat source can be considered as very attractive and the ejection cycles becomes truly competitive in comparison with the absorption refrigeration systems.

Chapter 6 presents a review of refrigerants and its historical evolution. The authors present the main characteristics and properties that characterize the refrigerants and discussed the different replacement possibilities for the currently most used refrigerants. The authors address the issue of the most promising refrigerants to be used in future.

Chapter 7 presents an experimental analysis about the retrofitting of two commercial stationary refrigeration systems marketed by an Italian leading company of the sector. The authors examine the performance of R410a and R407f as effective alternatives to R404a due to their compatibility, non-flammability and market availability.

Chapter 8 examines the performance of a transcritical cycle that has been evaluated with a prototype R744 system working as classical split-systems to cool air. The authors argue that Carbon dioxide (R744) is a valid alternative to classical substances such as HFCs used in vapor compression plants. The experimental transcritical cycle has been examined in comparison with a classical vapor compression plant working with the R134a.

Chapter 9 addresses the issue of the use of a capillary tube as an expansion device, with particular reference to CO<sub>2</sub> (R744) transcritical heat pump system. The authors contend that capillary tubes which are extensively used in small size vapor compression systems work very differently in a CO<sub>2</sub> transcritical heat pump system. The authors suggest that there is an optimal length of capillary tube for a given diameter at which the heat pump runs optimally.

Chapter 10 examines the challenges and opportunities of the use of transcritical CO<sub>2</sub> refrigeration system in tropical region. The authors present a discussion on component design and system level performance analysis.

Chapter 11 presents the principles and methods of holistic understanding of the foodstuff freezing process, as well as structure, functioning and development of refrigeration systems. The author examines the modern classification of frozen products, new methods of research of freezing process as well as selection, accumulation and systematization of general principles of refrigeration technology implementation

Chapter 12 analyses the influence of process variables on thermal and microbiological behavior of minimally processed foods submitted to refrigeration process with and without evaporative cooling effect. The author ground his arguments by means of two case studies.

Chapter 13 presents a brief historical context followed by an overview of the technologies used for fruits and vegetables storage, including refrigerated and controlled atmosphere storage as well as the most recently developed technologies for storing these produces. The authors present the current recommendations for long term storage using ‘Rocha’ pear as a case study.

## **Preface**

Chapter 14 identifies the existing challenges on the proper design of evaporators to mitigate contamination-related risks in air blast freezing systems. The authors identify the importance of evaporator coils, fins and drain pans in blast freezers as a source of microbial, physical and chemical contamination. The authors discuss contamination problems specific to the key components of blast freezers and measures for contamination control are discussed.

Chapter 15 presents an experimental study on the effects of some of the most important variables that affect the infiltration rate in open refrigerated vertical display cases at steady operation. The authors also analyze and compare methods to measure the air infiltration rate.

Chapter 16 presents an overview about experimental studies concerning the thermal performance of air curtains and heat exchangers installed in vertical open refrigerated display cases.

The authors identify the role of the discharge air grille and the perforation density of the back panel on the thermal performance of the air curtain.

Chapter 17 examines two experimental case studies on domestic refrigerators without modifying its cooling performance. In the first case, the authors analyze the thermal profile in the compartments of a refrigerator. In the second case, the authors propose a new material as thermal insulator.

Chapter 18 addresses the issue of hygienic imperatives in the evaporator design, with particular reference to the frosting and defrosting phenomena. The authors address the methods and patterns of evaporator defrosting as affected by hygienic design implications and criteria. The authors present the advantages and drawbacks of diverse defrost methods with regards to contamination risks in refrigeration facilities.

Chapter 19 discusses the use of expander mechanisms to recover the expansion energy of refrigeration systems. The authors present and discuss an array of techniques that help in achieving this purpose.

Chapter 20 addresses the issue of cold thermal energy storage. The authors discuss the benefits as well as the classification and operating strategies of this technology. The authors paid special attention to the analysis of specific features of heat transfer phenomena in ice storage tank and present the sizing of ice thermal storage system for different operating strategies.

Chapter 21 presents a high efficiency heat pump system using for cold storage and heating. Based on experimental and numerical results, the author contends that in order to improve the coefficient of performance, one can use a thermobank that stores the wasted heat during refrigeration cycles and an ejector to decrease the compressor displacement.

Chapter 22 presents and analysis the availability of a number of smart engineering solutions and control strategies to exploit the employment of renewable energy in the food storage sector. The authors argue that it is possible to reduce the energy consumption of refrigerated warehouses and hence the global energy demand, if adequate importance is placed on the integration of renewable resources in the energy supply of large cold storage facilities.

Chapter 23 identifies the existing challenges in the natural gas liquefaction techniques. After reviewing the trends in the natural gas optimization area, the authors identify future research directions.

Chapter 24 presents an alternative refrigeration system based on fuel cells. The authors give a description of the fuel cell model and present examples of the energy load profiles impact on the fuel cells sizing, hydrogen consumption and system autonomy. The authors examine the economical feasibility of this new refrigeration system linked to renewable energies and present an economical assessment for different scenarios.

In conclusion, the Handbook of Research on Advances and Applications in Refrigeration Systems and Technologies, accounting with the contribution of 60 authors from 16 countries, intends to be a reference book for all interested parties, from undergraduate students, practicing engineers, researchers

and decision-makers. This Handbook aims to cover more refrigeration aspects, presenting the results of ongoing research and defining paths for the future evolution of refrigeration equipment and systems.

The main output of the Handbook is related to the improvement of energy efficiency in the refrigeration sector, and simultaneously contributing for its sustainability. Additionally, it gives particular relevance to nowadays topics such as innovative technologies, energy efficiency, environmental impact, sustainability, legislation and policy.

We hope that you enjoy the reading.

The Editors,

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