

Absorption Refrigeration and Thermochemical Energy Storage

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His research focuses on sustainable energy technologies, specifically encompassing absorption heat pump systems, energy metamaterials, and fuel cell technologies. Dr. Luo has authored over 50 peer-reviewed publications and holds more than 20 patents. He currently directs 11 research projects, which are supported by major national bodies including the National Key R&D Program and the National Natural Science Foundation of China.

At USTB, he teaches undergraduate and graduate courses such as Engineering Fluid Mechanics and Novel Energy Systems. Additionally, he serves as a regular reviewer for international journals in the energy sector, including *Energy*, *Renewable Energy*, and *Applied Thermal Engineering*.

PREFACE

1. The Cooling-Energy-Climate Nexus: A Contemporary Challenge

The relationship between cooling demand, energy consumption, and climate change constitutes one of the most complex challenges in sustainable development. The International Energy Agency projects that global energy demand for space cooling and refrigeration will triple by 2050. This book addresses this challenge through a systematic examination of absorption refrigeration technology coupled with thermochemical energy storage systems. Unlike conventional vapor compression refrigeration, which depends on mechanical work input and relies on synthetic refrigerants with high global warming potential, absorption systems utilize thermal energy as the primary input and employ working fluids including green refrigerant with minimal environmental impact.

2. Motivation and Rationale

Despite a 150-year history and the unique ability to utilize low-grade waste heat and renewable energy, absorption refrigeration currently accounts for less than 5% of the global market. Its limited adoption is primarily due to higher capital costs, a larger physical footprint, and lower efficiency compared to evolving vapor compression systems. However, as the global energy landscape shifts, the inherent advantages of absorption cycles—particularly their compatibility with natural refrigerants—are positioning the technology for a significant resurgence.

Three pivotal developments are catalyzing this renaissance: first, the stringent enforcement of international protocols such as the Kigali Amendment; second, the burgeoning demand for high-density thermal energy storage to mitigate renewable intermittency; and third, the emergence of AI-driven molecular design, which is accelerating the discovery of high-performance, non-toxic refrigerants. Despite these advancements, there remains a critical lack of comprehensive literature integrating classical thermodynamics with modern innovations like ionic liquids and machine learning. This work addresses that gap, providing a systematic foundation for the next generation of absorption technology.

3. Organization and Structure

The book comprises seven chapters organized to provide progressive development of concepts while enabling each chapter to serve as a standalone reference for specific topics.

Chapter 1: Fundamental Theory and Overview establishes the theoretical and contextual foundation. The chapter reviews the historical development of absorption technology, presents fundamental thermodynamic principles. This chapter provides the necessary context for

understanding subsequent technical content.

Chapter 2: Working Principle of Absorption Refrigeration presents a rigorous explanation of absorption cycle operation. The treatment encompasses single-effect, double-effect, and triple-effect configurations, with detailed descriptions and thermodynamic modeling methodologies.

Chapter 3: Working Pairs and Properties for Absorption Refrigeration and Energy Storage systematically reviews conventional and emerging working fluids. The discussion includes alternative inorganic absorbents, organic absorbents, and novel materials including ionic liquids.

Chapter 4: Novel Absorption Refrigeration Technology examines advanced cycle configurations and system innovations. Topics include single/double effect cycle, absorption-compression hybrid systems, and integrated solid-state hydrogen storage peak shaving techniques. This chapter details the performance enhancement approaches developed in our research project, demonstrating their practical effectiveness in optimizing system efficiency.

Chapter 5: Absorption Thermochemical Energy Storage Technology represents a distinctive contribution of this work. The chapter presents a systematic treatment of thermochemical energy storage principles, working pair selection for storage applications, and seasonal storage implementations. The integration of cooling and storage functions is examined from both thermodynamic and system design perspectives.

Chapter 6: Low-temperature Proton Exchange Membrane Fuel Cell and Absorption Refrigeration Coupling System presents a detailed explanation of hybrid systems, including energy matching methodologies and experimental performance data. Such system design enables efficient recovery of waste heat, thereby enhancing the overall performance of hydrogen fuel cell vehicles.

Chapter 7: AI Applications for Working Medium Pair Prediction introduces data-driven methodologies for materials discovery. The chapter presents machine learning fundamentals, molecular representation techniques, graph neural network (GNN) architectures, and case studies demonstrating the prediction of thermophysical properties and the identification of novel working pairs. Finally, marking a paradigm shift towards AI-for-Science in thermal management.

4. Intended Readership and Utilization

Graduate Students: Read Chapters 1-3 for a foundation, then select chapters based on your thesis or coursework.

Researchers & Academics: Use chapters as standalone references; pay close attention to identified "future directions" for new research opportunities.

HVAC/Renewables Engineers: Focus on Chapters 2, 4, and 6 for design methodologies, performance data, and case studies.

Policy Analysts & Planners: Consult Chapters 1, 4, 5, and 6 for technology assessments and decarbonization strategies.

Materials Scientists & Chemists: Prioritize Chapters 3 and 7 for working fluid properties and computational discovery methods.

5. Acknowledgments

The authors would like to express their sincere gratitude for the financial support from the International Sci. & Tech, Collaboration Program of Guangdong Province, China (Grant No 2023A0505050157). This funding has been instrumental in facilitating the international academic exchange and collaborative research that form the foundation of this monograph.

Beyond the financial support, this work is the result of years of dedicated research at the Energy and Environmental Engineering Laboratory. I would like to express my deep indebtedness to my colleagues and research team members for their invaluable insights, rigorous critiques, and technical assistance during the experimental and modeling phases of this work.

Special thanks are also extended to the peer reviewers and the editorial team at Macao Scientific Publisher whose professional guidance helped refine the structure and clarity of the manuscript. It is my sincere hope that the methodologies and insights distilled within these pages will serve as a foundational resource for the next generation of engineers and researchers, catalyzing the transition toward a sustainable, cooling-resilient future.

LIST OF ABBREVIATIONS / NOMENCLATURE

List of Abbreviations

Abbreviation/Symbol	Definition
AHP	Absorption Heat Pump
ACHR	Absorption-Compression Hybrid Refrigeration
COP	Coefficient of Performance
ECOP	Exergetic Coefficient of Performance
SHX	Solution Heat Exchanger
LSHX	Low-pressure Solution Heat Exchanger
HFOs	Hydrofluoroolefins
HSHX	High-pressure Solution Heat Exchanger
BMIM	1-Butyl-3-methylimidazolium
MMIM	1-Methyl-3-methylimidazolium
EMIM	1-Ethyl-3-methylimidazolium
DMP	Dimethyl phosphate
ILs	Ionic Liquids
T_G	Generator temperature (K)
T_E	Evaporator temperature (K)
T_0	Reference temperature (K)
P_0	Compressor pressure (kPa)
P_A	Absorber pressure (kPa)
P_E	Evaporation pressure (kPa)
c_G	Generation concentration
Q_G	Heat load in generator (kW)
Q_E	Heat load in evaporator (kW)
Q_{HG}	Heat load in high-pressure generator (kW)
W	Compressor work (kW)
f	Concentration difference (%)
E_x	Effectiveness of solution heat exchanger

List of Nomenclature

Symbol	Description	Unit
T	Temperature	$^{\circ}\text{C}$ or K
P	Pressure	kPa or MPa
m	Quality	g or kg
$C_p(c_p)$	Specific heat capacity at constant pressure	$\text{J}\cdot\text{g}^{-1}\cdot\text{K}^{-1}$
v	Corrosion rate	mm/a (or $\text{mm}\cdot\text{a}^{-1}$)
w	Mass fraction (Concentration)	$\text{wt.}\%$
$x(y)$	Mole fraction	—
pH	Acidity or alkalinity of a solution	—
D	Diffusion coefficient	cm^2/s
ρ	Density	$\text{g}\cdot\text{cm}^{-3}$
η	Dynamic viscosity	$\text{mPa}\cdot\text{s}$
a_w	Water activity	—
t	Immersion time / Exposure time	h or d

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Fundamental Theory and Overview

1.1 Development of Absorption Refrigeration Technology

Absorption refrigeration technology emerged in the 19th century as a significant branch in the evolution of refrigeration technologies. Unlike vapor-compression refrigeration, absorption refrigeration utilizes thermal energy—such as steam, hot water, or fuel gas—as the driving force. This system achieves cooling through the absorption and desorption cycles of working fluid pairs, primarily ammonia-water and lithium bromide-water, while offering benefits such as energy efficiency, environmental sustainability, minimal noise operation, and waste heat recovery capabilities.

In 1810, Scottish scientist John Leslie pioneered the first batch-type absorption refrigeration unit. By 1859, French engineer Ferdinand Carré established and refined the principles of the ammonia-water absorption refrigeration system. He secured patents for this innovation in France (1859) and the United States (1860). His refrigeration device, capable of continuous ice production, is recognized as the foundation of modern absorption refrigeration technology. Commercial implementation of absorption refrigeration commenced during the late 19th and early 20th centuries. The Carré Company initiated mass production of absorption ice-making machines, distributing them throughout Europe and the Americas. In 1930, Arkla introduced compact single-effect gas-fired air conditioners to the market. A significant milestone occurred in 1945 when Carrier Corporation developed the world's first single-effect lithium bromide absorption refrigeration unit with a 523 kW cooling capacity. This lithium bromide-water system catalyzed the transition of absorption refrigeration from ice-making to air conditioning applications. Following the 1973 oil crisis, global attention shifted toward energy conservation and alternative energy utilization. Japan, European nations, and the United States intensified research and development efforts for high-efficiency absorption refrigeration systems. In 1974, U.S. production of lithium bromide absorption refrigeration units peaked at 1,000 units. Subsequently, in 1977, Japan's Ebara Corporation engineered an energy-efficient absorption refrigeration unit that reduced energy consumption by 20-30%. Other manufacturers followed suit with similar energy-efficient models, which currently constitute over half of total absorption refrigeration unit production.

China's engagement with absorption refrigeration technology began in the 1950s. The country manufactured its first lithium bromide absorption refrigeration unit in 1954, establishing a robust

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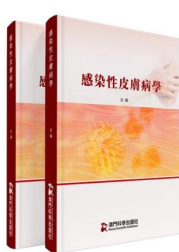


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- 實用小兒內科學 Practical pediatric internal medicine
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