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Not-in-kind cooling technologies: A quantitative comparison of refrigerants and system performance

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ABSTRACT

With advances in solid-state cooling materials in the past decade, non-vapor compression technologies, or not-in-kind (NIK) cooling technologies have garnered great attention. Therefore, a universal performance index is urgently needed to compare these NIK technologies with each other and vapor compression cooling as well. In this study, a systematic method is developed to visualize the contributions to the coefficient of performance (COP) from materials (working fluids) level to the system level as a function of temperature lifts. Since the materials level COP depends solely on the materials properties under the specified cycle, it can be used for comparing refrigerants for all NIK technologies. We chose the water-cooled water chiller operating under identical conditions as the basis for the system performance comparison of all NIK cooling technologies. Upon normalizing the system COP to the Carnot COP, its variation with the system temperature lift reveals the intrinsic potential applications for each NIK cooling technology.

Technologies de refroidissement alternatives: une comparaison quantitative des frigorigènes et de la performance du système

Mots clés : Magnétocalorique ; Elastocalorique ; Thermoélectrique ; Stirling ; Electrocalorique ; Compression de vapeur

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Nomenclature

A	materials constant related to hysteresis [J·g^{-1}]
AMR	active magnetic regenerator
CFCs	chlorofluorocarbons
COP	coefficient of performance [–]
c_p	specific heat [J·g^{-1}·K^{-1}]
D	electric displacement [C·m^{-2}]
E	electric field intensity [N·C^{-1}]
HCFCs	hydrochlorofluorocarbons
HVAC	heating, ventilating, and air-conditioning
H	magnetic field [A·m^{-1}]
h	specific enthalpy [J·g^{-1}]
I	current [A]
k	thermal conductivity [W·m^{-1}·K^{-1}]
L	latent heat [J·g^{-1}]
l	length [m]
Δm	magnetic moment change [A·m^2·kg^{-1}]
NIK	not-in-kind
p	pressure [MPa]
P	polarization [C·m^{-2}]
q	capacity per unit mass [J·g^{-1}]
RCP	relative cooling power [J·g^{-1}]
SMAs	shape memory alloys
s	specific entropy [J·g^{-1}·K^{-1}]
T	temperature [K]
T_c	cold side (heat source) temperature for a heat pump [K]
T_h	hot side (heat sink) temperature for a heat pump [K]
v	specific volume [m^3·kg^{-1}]
w	work per unit mass [J·g^{-1}]
x	length [m]
Z	thermoelectric materials figure-of-merit [K^{-1}]
α	Seebeck coefficient [V·K^{-1}]
ε	strain [–]
ρ	resistivity [Ω·m]
γ	non-dimensional latent heat [–]
σ	uniaxial stress [MPa]
$\mu_0 H$	magnetic field [Tesla, or T]
Φ_{mat}	normalized materials level COP, or materials exergetic efficiency [–]
Φ_{sys}	system exergetic efficiency (normalized to materials COP) [–]
ΔT_{lift}	system temperature lift [K]
$\Delta T_{approach}$	heat exchanger approach temperature [K]

1. Introduction

Vapor compression cooling systems are operated as reverse Rankine cycle while utilizing refrigerant liquid–vapor phase change, and they dominate use in heat pumps, air-conditioners and refrigerators around the world. The term of not-in-kind (NIK) cooling technologies refers to any alternative cooling systems other than the vapor compression cooling systems that are most commercially dominant today. As indicated by Fig. 1, different materials may be used, such as solid-state materials (shape memory alloys, magnetic materials and ferroelectric materials), gases (air) and even liquids. Even the liquid–vapor phase change materials themselves can be applied in a variety of different cycles. For example, absorption/adsorption cooling uses the heat to drive the cycle instead of compressors in vapor compression systems.

Pursuit of NIK cooling/heating technologies has a long history. When the heating–ventilating–and-air-conditioning (HVAC) industry were seeking for alternatives to the chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) regulated by the Montreal Protocol, Fischer et al. (1994)

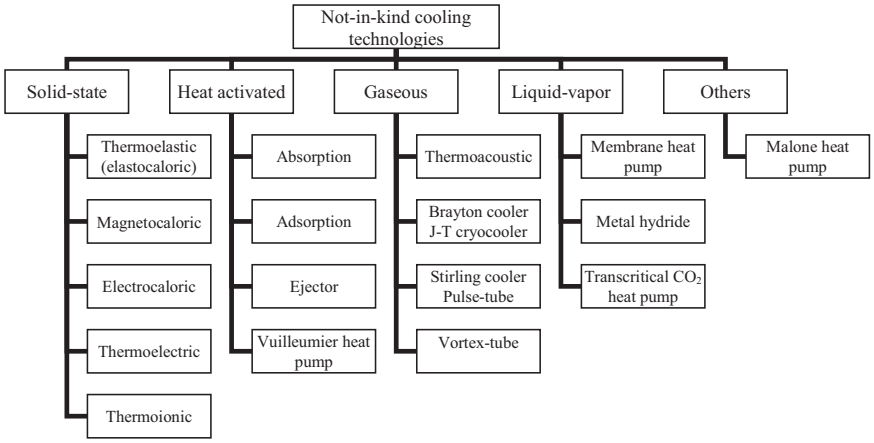

Fig. 1 – Various categories of not-in-kind cooling technologies.