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Analysis of a nano-scale thermo-acoustic refrigerator

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ABSTRACT

Purpose of this study is to analyze a nano scale thermo-acoustic refrigeration cycle in terms of its thermodynamic performance. A nano scale thermo-acoustic refrigerator operating with Maxwell–Boltzmann gas and He^4 is chosen as the working fluid is considered. Thermo-size effects that are dominant at the nano scale are taken into account too. In addition, a new thermo environmental method identified as modified ecological function for the refrigeration cycles is proposed. Considered system are analyzed with this new proposed method as well as basic thermodynamic criteria including COP, cooling load, work input and entropy generation. Results are obtained numerically and presented.

Analyse d'un réfrigérateur nanométrique thermo-acoustique

Mots clés : Échelle nanométrique ; Thermo-acoustique ; Froid ; Fonction écologique modifiée

1. Introduction

Currently, there is increasing trend toward the use and the design of more effective heat engines and refrigerators. Therefore, improving the performance and efficiency of refrigerators has become an obligation. The use of alternative energy sources or the development of new technologies can be investigated as two possible solutions. In this paper, thermo-acoustic refrigerators that make possible to cool any place by means of sound wave are the subject of investigation.

One way to obtain more efficient thermal cycles is to apply finite-time thermodynamic (FTT) proposed by Curzon-Ahlborn and Novikov. They presented an endoreversible heat engine called as Curzon–Ahlborn–Novikov (CAN) engine (Curzon and Ahlborn, 1975; Novikov, 1958). Following the development of

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Nomenclature

A	area [m^2]
ec	classical ecological function [J]
E	modified ecological function [J]
F	free energy [J]
H	enthalpy [J]
m	mass [kg]
N	number of particles
S	entropy [JK^{-1}]
Q	heat [J]
T	temperature [K]
V	volume [m^3]
P	pressure [kPa]
U	internal energy [J]
W	work input [J]
x	pressure ratio

Subscripts

A	amplitude
H	high
gen	generation
L	low
m	mean
o	environment
R	refrigerator

Greek letters

φ	coefficient of performance
λ	coefficient of performance of reversible refrigeration cycle

FTT, new criteria were submitted by several authors to evaluate the thermal cycles. The most widespread criterion was submitted by Angulo-Brown (1991) and improved by Yan (1993). Some examples of the refrigeration cycles with FTT and ecological as well as thermo-acoustic cycles can be found in references Acikkalp (2013), Chen et al. (2005, 2007a, 2007b, 2007c, 2009, 2012), Huang et al. (2008), Kan et al. (2011), Li et al. (2009, 2011), Sisman and Muller (2004), Tyagi et al. (2002), Wu et al. (2003, 2009, 2010), Yan and Lin (2000), and Zhu et al. (2005a, 2005b, 2006a, 2006b). In references Acikkalp (2013), Chen et al. (2005, 2007a, 2007b, 2009, 2012), Huang et al. (2008), Li et al. (2009, 2011), Tyagi et al. (2002), Wu et al. (2009), Yan and Lin (2000), and Zhu et al. (2005a, 2005b, 2006a, 2006b), conventional refrigeration cycles were investigated with ecological function. Huang et al. (2008) evaluated the performance of irreversible four-temperature-level heat pump. They found that the ecological optimization makes the entropy generation rate decrease 76.8%, the coefficient of performance increase 33.6% and the heating load decrease 53.7%. An irreversible three-temperature-heat source refrigerator was researched by Yan and Lin (Yan and Lin, 2000). They reported that using the ecological optimization criterion to investigate the optimal performance of an irreversible three-heat-source refrigerator is effective and advantageous. In Chen et al. (2005, 2007a), an irreversible Carnot refrigeration cycle and an irreversible Carnot heat pump were optimized with exergy-based ecological function and these results are obtained for refrigeration cycle and heat pump respectively; exergy output rate decreased about 17%, the cooling load decreased about 16%, the COP increased about 8% and the entropy generation rate decreased about 30% and the exergy-output rate decreased about 16.6%, the COP increased about 16%, and the entropy-generation rate decreased about 40%. In Chen et al. (2007b, 2009, 2012), Li et al. (2009, 2011), and Zhu et al. (2005a, 2005b, 2006a, 2006b), exergy-based ecological function is used for investigation of the irreversible and endoreversible refrigeration cycles with different heat transfer laws. They asserted that ecological function had advantageous thermodynamical criterion. Tyagi et al. (2002) researched Stirling and Ericsson heat pump with ecological function. Considered heat pumps are assumed as operating with finite heat reservoir. Acikkalp (2013) investigated four-temperature-level absorption refrigerator and suggested a novel criterion. Wu et al. (2009, 2010) studied micro thermoacoustic micro refrigeration and heat engine cycles operating with ideal Bose gas. Wu et al. (2003) analyzed and made optimization of an irreversible thermocoustic engine, which is used generalized heat transfer laws, with FTT. Chen et al. (2007c) evaluated an irreversible thermoacoustic cooler by using exergetic efficiency. In Chen et al. (2012) and Kan et al. (2011), irreversible thermoacoustic cooler and heat engines were analyzed with finite-time exergoeconomic criterion.

Nano thermal cycles may be an alternative for more efficient thermal cycles. Interests of researchers about the nano scale thermal cycles have risen for last decades, because of the fast development in the nano science and technology. However, thermo-size effects should be considered, because of important influences on the thermal properties. In Babac and Sisman (2011a), Firat et al. (2010), Ozturk et al. (2011), Sisman (2004), Sisman and Babac (2012), Sisman and Muller (2004), and Sisman et al. (2007), thermal properties of quantum gases are investigated deeply regarding thermo-size effects. As a result of this, some papers can be found about assessment of nano scale thermal cycles in Açıkkalp and Caner (2015a, 2015b, 2015c, 2015d), Babac and Sisman (2011a, 2011b), Guo et al. (2012), Nie and He (2008, 2009), Nie et al. (2008), and Şişman and Saygin (2001). Nano/micro thermal cycles operating with Maxwell–Boltzmann gases are studied in Açıkkalp and Caner (2015a, 2015b), Nie and He (2008, 2009), and Nie et al. (2008). Some cycles investigated are Brayton, Carnot, refrigeration and dual cycles. They are aimed to obtain maximum performance conditions. Similarly, thermal cycles operating with Bose and Fermi gas under different degeneracy conditions are investigated to obtain their performance characteristics (Açıkkalp and Caner, 2015c, 2015d; Guo et al., 2012; Şişman and Saygin, 2001). Babac and Sisman (2011b) analyzed for heat engine and refrigeration cycles considering thermosize effects. Their work output, efficiency and coefficient of performances are studied to obtain the most efficient performance.

In this paper, we analyze a nano scale thermo-acoustic refrigerator as an alternative thermal device. Working fluid of the nano scale refrigeration cycle operating with Maxwell–Boltzmann gas (He^4) and thermo-size effects that affect thermal behavior of the gas in the nano scale are considered too. In addition, we propose a modified ecological function to assess refrigeration cycles and use it first time at the thermo-acoustic refrigerator. Classical ecological function considers work output and exergy